OF INVESTIGATION 42

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RNER, Governor

DEPARTMENT OF REGISTRATION AND EDUCATION
WILLIAM SYLVESTER WHITE, Director

Severe Rainstorms in Illinois 1958-1959

by F. A. HUFF and S. A. CHANGNON, Jr.

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, Chief

URBANA
1961

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STATE WATER SURVEY DIVISION
WILLIAM C. ACKERMANN, *Chief*

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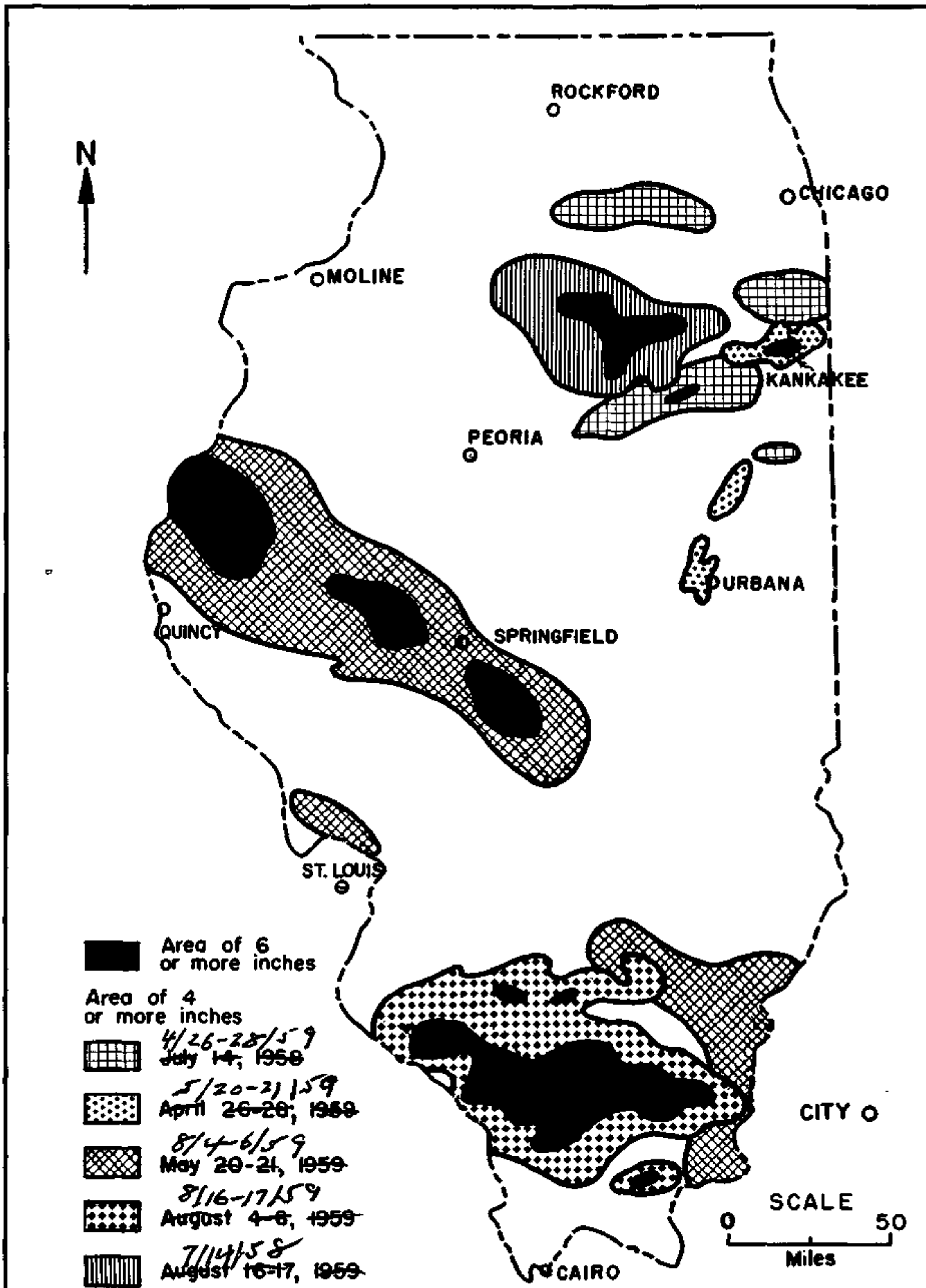


Figure 1. Location map for severe rainstorms in Illinois, 1958-59

Severe Rainstorms in Illinois
1958-1959

by F. A. Huff and S. A. Changnon, Jr.

INTRODUCTION

As part of its hydrometeorological program, the State Water Survey operates four concentrated raingage networks within the state on areas ranging in size from 10 to 550 square miles. These networks have provided a large amount of data pertaining to rainfall relations on small watersheds, the variability of rainfall in time and space, and the measurement requirements for the collection of accurate rainfall data. This is a continuing program and the results for the period 1948-56 were summarized in Water Survey Bulletin 44.[1]

Excessive operational costs, however, do not permit the widespread installation of concentrated raingage networks throughout the state. Consequently, since 1948 the State Water Survey has conducted field surveys of large-scale, severe rainstorms in Illinois to supplement climatological network observations and to provide pertinent information for use in hydrologic analyses, design, and planning. These field surveys provide detailed information on the distribution of rainfall in severe storms over thousands of square miles, which cannot be obtained from the climatological network operated by the U. S. Weather Bureau that in Illinois consists of approximately 1 raingage per 225 square miles. The field survey data are used in conjunction with synoptic weather data and radar observations to perform detailed analyses of the characteristics of each storm, and the results are made available to interested users as reports of investigation. This report is the fifth in this series.[2, 3, 4, 5]

Three field surveys were conducted during 1958-59. The first was made on a storm centered near Ottawa in northern Illinois on July 14, 1958 (Fig. 1). Maximum rainfall amounts of 8 to 9 inches occurred at the core of the storm within a 12-hour period, and more than 7 inches fell within a 6-hour period. Normal monthly rainfall in this region for July is less than 3 inches.

The second field survey was made following the storm of May 20-21, 1959, in eastern Illinois. In this storm, which was centered on a line from Champaign-Urbana to Kankakee (Fig. 1), 6-hour amounts in excess of 6 inches were observed, and 3-hour amounts exceeded 4 inches within the storm core. A portion of the storm core was centered on an urban network of 10 recording and 4 nonrecording gages in Champaign-Urbana, operated by the State Water Survey in cooperation with the Civil Engineering Department of the University of Illinois. An unusually detailed analysis was made possible by this network data and should provide valuable information to engineers involved in urban storm drainage problems.

The third field survey was conducted on the storm of August 16-17, 1959, which was centered in the region from Sparta to Harrisburg in southern Illinois (Fig. 1). This storm was centered on the Water Survey's concentrated network of 54 raingages in 550 square miles in southern Illinois, a very fortunate occurrence for researchpurposes in that this provided details on severe rainstorm characteristics rarely available. Amounts exceeded 10 inches in 16 hours in the storm core.

In addition to the three storms discussed above, two storms for which field surveys were not made are included in this report. The storm on April 26-28, 1959, is included because of its unusual severity for northeastern and north central Illinois at that time of the year (Fig. 1). Also, a portion of the heaviest rainfall occurred on the Water Survey's concentrated raingage network on the Panther Creek watershed in north central Illinois. Amounts in excess of 6 inches were recorded within a 36-hour period in this early spring storm.

Total rainfall amounts and rainfall intensities in the storm of August 4-6, 1959, were not rare, but the unusually large area of heavy rainfall which stretched from western to southern Illinois (Fig. 1) made this storm of particular interest. Amounts exceeded 6 inches in 60 hours at several locations in Illinois, while in eastern Iowa 9-inch amounts occurred during the night of August 5-6. The large area of heavy rainfall made a field survey unfeasible with available personnel. Fortunately, most of the Illinois portion of the storm was in a region where the number of raingages in the climatological network is above average.

In the analysis of each storm in this report, isohyetal maps for the total storm period have been prepared, and where the density of recording gages has permitted it, isohyetal maps for incremental periods of peak rainfall within the total storm period have been made. From the isohyetal maps, area-depth relations have been established for the total storm period and for peak periods of rainfall within the overall storm. When possible, the time distribution of rainfall in the storms was determined also.

Other analyses include the construction of mass rainfall curves for stations near the storm cores, evaluation of the synoptic weather conditions associated with each storm, radar analysis of the storm characteristics, and a description of antecedent rainfall conditions. For the two storms centered on or near concentrated raingage networks, rainfall-runoff relations are presented. Discussions of the five storms are presented in chronological order.

None of the storms described in this report had depth-duration-area values that exceeded those presented on page 77 of Water Survey Report of

Investigation No. 35.[5] Only the storm of August 16-17, 1959, had amounts which approached these envelope values.

Radar observations of the storms were made with a CPS-9 radar operated by the State Water Survey at the University of Illinois Airport near Urbana in east central Illinois (Fig. 1). This is a high-powered, 3-cm set, specifically designed for the detection, tracking, and general meteorological analysis of storms. The CPS-9 has an effective observation range of about 250 miles, although on occasions this range may vary considerably, depending upon storm characteristics, precipitation attenuation, and other atmospheric conditions.[5]

Acknowledgments

This report was prepared under the general direction of William C. Ackermann, Chief of the Illinois State Water Survey, and Glenn E. Stout, Head of the Meteorology Section.

Credit is due various personnel in the following organizations for providing rainfall data pertinent to the study: U. S. Weather Bureau offices at Asheville, North Carolina, and Champaign-Urbana, Illinois; the U. S. Geological Survey, and the Illinois Division of Waterways. Appreciation is expressed to Mr. Hal Foster, U. S. Weather Bureau, Kansas City, for providing valuable radar data used in the analysis of the storm of August 16-17, 1959, and to Mr. Lars Christensen, U. S. Weather Bureau, Springfield, Illinois, and personnel of Chanute Air Force Base for providing synoptic weather data essential to the study. The assistance of Mr. Warren Daniels of the U. S. Geological Survey is gratefully acknowledged for furnishing streamgage data and for his suggestions pertaining to analysis of these data. Dr. Floyd Cunningham of Southern Illinois University supplied rainfall data for the August 16-17, 1959, storm compiled from a network of raingages in southern Illinois operated by Southern Illinois University.

Radar data were collected at the Water Survey's Meteorology Laboratory with an AN/CPS-9 radar which was supplied by the U. S. Army Signal Research and Development Laboratory under Contract DA-36-039 SC-75055.

STORM OF JULY 14, 1958

The most severe rainstorm in Illinois during 1958 was centered near Ottawa in the northern part of the state on July 14, when 12-hour rainfall amounts of 8 to 9 inches and 6-hour amounts in excess of 7 inches were recorded. Rainfall exceeding 6 inches fell over an area of 500 square miles, 4 inches over 2000 square miles, and 2 inches over 4800 square miles. Although very intense, this storm did not extend over as large an area as most of the severe rainstorms investigated previously A field survey was made of this storm to collect detailed data pertaining to the location, intensity, and orientation of the storm. Field survey data combined with that furnished by other organizations provided a total of 130 rainfall measurements upon which to base the storm analyses.

Isohyetal Patterns

An isohyetal map for the entire storm period is shown in Figure 2. All of the rainfall in the storm core and nearly all of it in the heavy rainfall region (Fig. 2) occurred within the 12-hour period beginning at 0000 CST, July 14. A few hundredths of an inch were added to the outer fringes of the storm zone in late afternoon and evening showers on July 14. Figure 3 shows the isohyetal pattern for the maximum 6-hour period of rainfall from 0030 to 0630 CST. The orientation of the storm is typical of severe rainstorms in Illinois, which have most frequent orientations from WNW-ESE through W-E to WSW-ENE. The space and time variability of the rainfall was so great that a 3-hour peak period map could not be determined satisfactorily from the available recording raingage data.

Depth-Duration-Area Relations

Area-depth relations for peak periods of 6 and 12 hours are given in Table 1. Over 80 percent of the total storm rainfall in the storm core occurred during the 6-hour period and, as mentioned earlier, all of it fell in 12 hours.

Table 2 shows the area which experienced rainfall amounts equalling or exceeding those for selected recurrence intervals for the 6-hour and 12-hour periods of maximum rainfall, based upon the frequency studies of Huff and Neill. For example, 400 square miles received amounts equalling or exceeding the 100-year frequency of point rainfall in this region during the maximum 6-hour rainfall period, while 550 square miles exceeded the 12-hour, 100-year frequency value.

Antecedent Rainfall

Total rainfall for the 5-day and 10-day periods preceding the July 14 storm is shown in the isohyetal maps of Figures 4 and 5. Normal rainfall for these 5-day and 10-day periods is approximately 0.5 inch and 1.0 inch, respectively. Figure 4 shows normal to slightly above normal amounts in the storm center in the Ottawa region with amounts of 0.50 to 0.75 inch for the 5 days preceding the storm. Only near the eastern end of the storm core in the vicinity of Kankakee was heavy rainfall experienced in the preceding 5 days. Figure 5 shows that 10-day totals preceding the storm of July 14 were near normal in the storm center in the Ottawa region, becoming above normal over much of the region surrounding the center.

TABLE 1

DEPTH-DURATION-AREA DATA, JULY 14, 1958

Duration (hours)	Depth (in.) for given area (sq. mi.) 10	25	50	100	200	500	1000	2000	5000	7500
6	7.70	7.50	7.25	6.95	6.50	5.55	5.00	4.00	2.70	--
12	8.95	8.70	8.50	8.20	7.40	7.00	6.20	5.25	3.85	3.10

TABLE 2

RECURRENCE INTERVAL OF MAXIMUM RAINFALL AMOUNTS, JULY 14, 1958

Duration (hours)	Area (sq. mi.) with rainfall equalling or exceeding given recurrence-interval values (yrs.) 2	5	10	25	50	100
6	3100	2300	1800	1200	750	400
12	4700	3800	2400	1600	950	550

Synoptic Weather

The surface map at 0000 CST, July 14, near the start of the heavy rainfall in the storm center, showed a warm front oriented approximately W-E through the storm zone from eastern Iowa to northern Ohio (Fig. 6). This front, which was located through extreme southern Illinois 24 hours earlier (0000 CST/July 13), moved northward through the state on July 13 and appeared to become nearly stationary temporarily in the storm zone. At 0600 CST, July 14, the front had moved little from its position 6 hours earlier, but it accelerated and dissipated rapidly in the next 6 hours, 0600-1200 CST. A strong inflow of moist maritime tropical air into Illinois existed during the storm period. At 0000 CST, July 14, air temperatures were near 75°F just south of the front in Illinois with dew points near 70 F. There appeared to be little temperature contrast across the front, but dew point differences of about 5°F existed. The isobaric pattern indicated considerable shear across the front at the time it entered the storm region. At 0000 CST on the 14th a cold front was approaching western Iowa, but was still about 500 miles west of the storm center.

The 850-mb chart for 1800 CST, July 13, indicated southwesterly flow of 10 to 20 knots throughout Illinois with relatively strong dew point gradients (Fig. 7). The storm zone was lying approximately parallel to the dew point lines. Convergence of moist air into northern Illinois was indicated by a 10-knot wind at Peoria, a few miles southwest of the storm center, compared to 25 knots at Columbia, Missouri, about 200 miles southwest of Peoria Wind speeds of 20 to 30 knots throughout the southern United States were bringing maritime tropical air northward. By 0600 CST, July 14, the wind flow pattern at 850 mb indicated relatively strong convergence into the storm region with Peoria reporting a WSW wind of 35 knots, while winds of 30 to 40 knots were blowing from the southwest in a zone from Oklahoma through southwestern and eastern Missouri, into central and northeastern Illinois and western Indiana. Winds to the east of this zone were also from the southwest but considerably lighter. Based on the 850-mb map at 0600 CST, the wind flow pattern was producing a maximum of convergence just east and northeast of Peoria in the rainstorm region.

The 700-mb map at 1800 CST on July 13 indicated westerly flow of approximately 25 knots through Illinois, and a minor trough oriented NW-SE through northern and northeastern Illinois in the vicinity of the storm region (Fig. 8). A minor trough at this level has been observed to occur frequently with severe rainstorms in Illinois. Figure 8 shows the storm region lying in an area of relatively strong dew point gradient with the dew point lines nearly parallel with the surface rainstorm axis, similar to the situation at 850 mb. By 0600 CST, July 14, the 700-mb winds indicated convergence into the storm region, with a WSW wind of 35 knots at Peoria becoming westerly at 25 knots over northern Indiana, while at the same time, southwesterly winds of about 35 knots were indicated throughout Missouri and central Illinois. Again, the storm region appeared to lie within the area of maximum convergence

At 1800 CST, July 13, the 500-mb map indicated WNW flow of about 35 knots in northern Illinois, and a NW-SE trough through the northeastern part of the state (Fig. 9). The storm region was lying m an area of relatively steep dew point gradient with the dew point lines again parallel to the rainstorm axis. By 0600 CST on the 14th the wind pattern over Missouri and Illinois indicated convergence east of Peoria, similar to conditions at 850 mb and 700 mb.

The 300-mb chart at 1800 CST, July 13 (Fig. 10), indicated slight divergence over Illinois in a weak ridge between two troughs to the west and east. By noon on the 14th changes in the wind patterns at 850 mb to 500 mb had removed the convergence zone east of Peoria, and the heavy rainfall in northern Illinois had ceased.

The precipitable water pattern for the layer from the surface to 400 mb at 1800 CST on July 13 is shown in Figure 11. This map shows the storm region lying slightly north of a ridge in the precipitable water pattern. A depth of approximately 1.4 inches is indicated in the storm zone which is about normal for mid-July. At Peoria the RAOB indicated 1.53 inches at that time. With the strong southerly flow of maritime tropical air at the lower levels, the precipitable water would be expected to increase by midnight, when the storm started. Figure 7 shows the isodrosotherms nearly perpendicular to the wind flow at 1800 CST, 6 hours prior to the start of the storm. RAOB data 12 hours later at 0600 CST indicated the expected increase had taken place. At that time the precipitable water depth at Peoria had risen to 2 06 inches, and the storm zone was part of a W-E ridge of precipitable water extending through central Iowa, northern Illinois, northern Indiana, and northern Ohio. The highest precipitable water depths in the country were along the axis of this ridge. The greatest increase in depth at Peoria during the nocturnal 12-hour period, 1800-0600 CST, was in the layer from the surface to 850 mb, where it increased from 0.65 to 1.02 inches. In the layer from 700 mb to 400 mb a negligible increase of 0.03 inch occurred in the 12-hour period.

The Showalter stability index for Peoria at 1800 CST, July 13, was +2. Values of +2 to +3 existed for several hundred miles to the north, east, and southeast, but values of -3 to -6 existed to the west and southwest in western Iowa, western Missouri, and Arkansas. The wind flow pattern at the surface and aloft indicated the movement of the more unstable air toward Illinois, and a decrease in stability would be expected as the night progressed. Reference to Showalter indices 12 hours later at 0600 CST indicated the presence of very unstable air over most of Illinois. Peoria had a value of -4 at that time, while Columbia, Missouri, to the southwest recorded a -5.

Radar Analysis

The CPS-9 radar set was not in operation during the period when most of the rainfall occurred. During the afternoon of July 13 two lines of echoes oriented approximately W-E were observed on the radar scope, one apparently associated with the northward-moving warm front and the other in the warm air to the rear of the front. When radar operations were terminated at 1800 CST, both lines were moving slowly northward, the first about 50 to 75 miles north of the radar station and the other a few miles south of the station. Neither line appeared to be intense or well defined.

Summary

The most severe rainstorm in Illinois during 1958, centered near Ottawa in northern Illinois, produced 12-hour amounts of 8 to 9 inches at the storm center and 6-hour amounts in excess of 7 inches. These amounts exceed the 100-year frequency of point rainfall in this region. Rainfall exceeding 6 inches fell over 500 square miles, 4 inches over 2000 square miles, and 2 inches over 4800 square miles during the total storm period.

Synoptic weather analyses indicated this storm occurred in the vicinity of a weak warm front which became nearly stationary during the storm period. The storm was supported by relatively strong convergence at the 850-mb to 500-mb levels, divergence at 300 mb, and a strong inflow of abnormally moist air in the lower levels. The storm dissipated when the front accelerated in its northward movement and wind flow changes removed the strong convergence zone. The maximization of rainfall at night and the WNW-ESE orientation of the rainstorm axis are typical characteristics of severe rainstorms in Illinois.

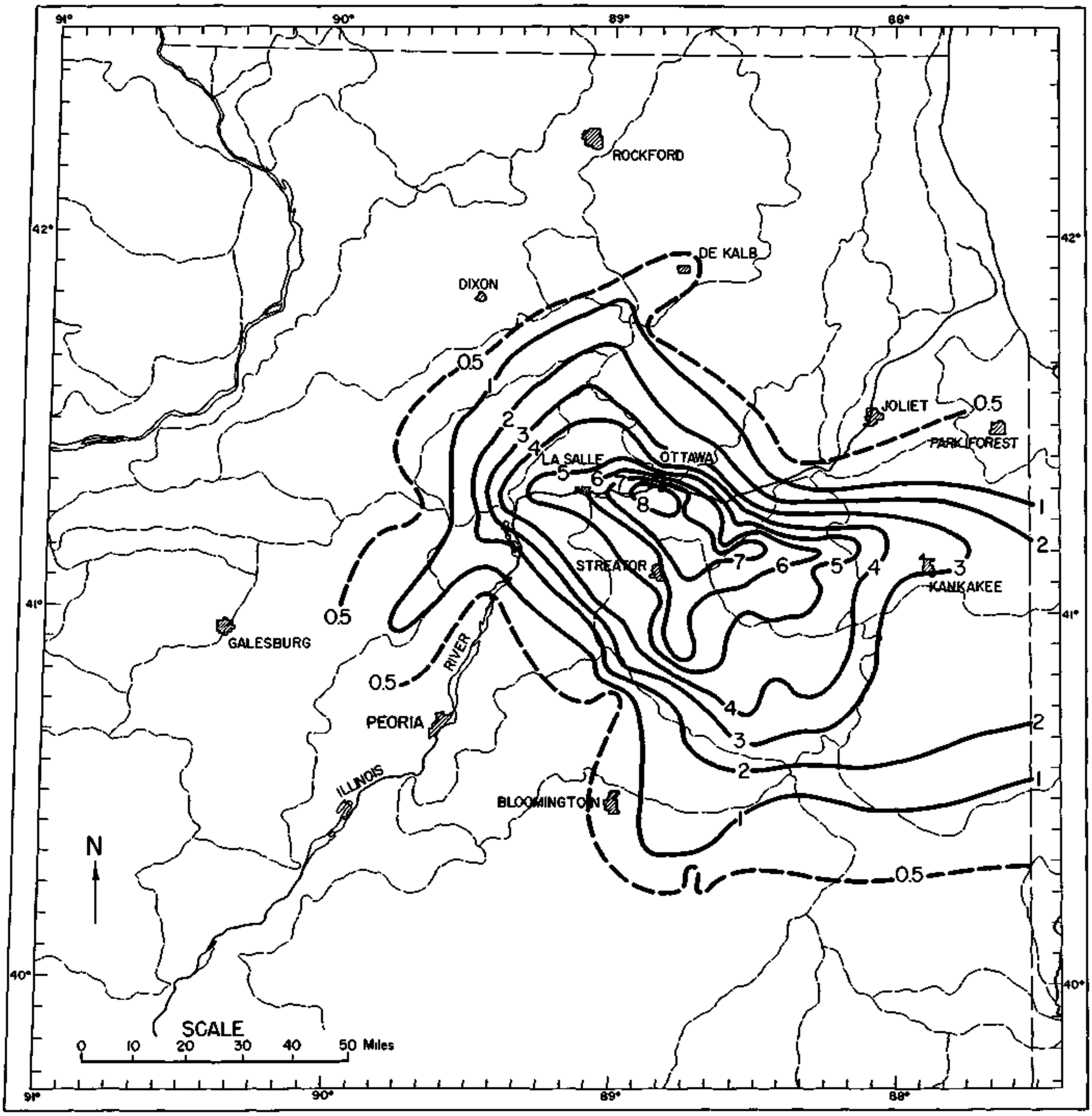


Figure 2. Total storm rainfall for July 14, 1958

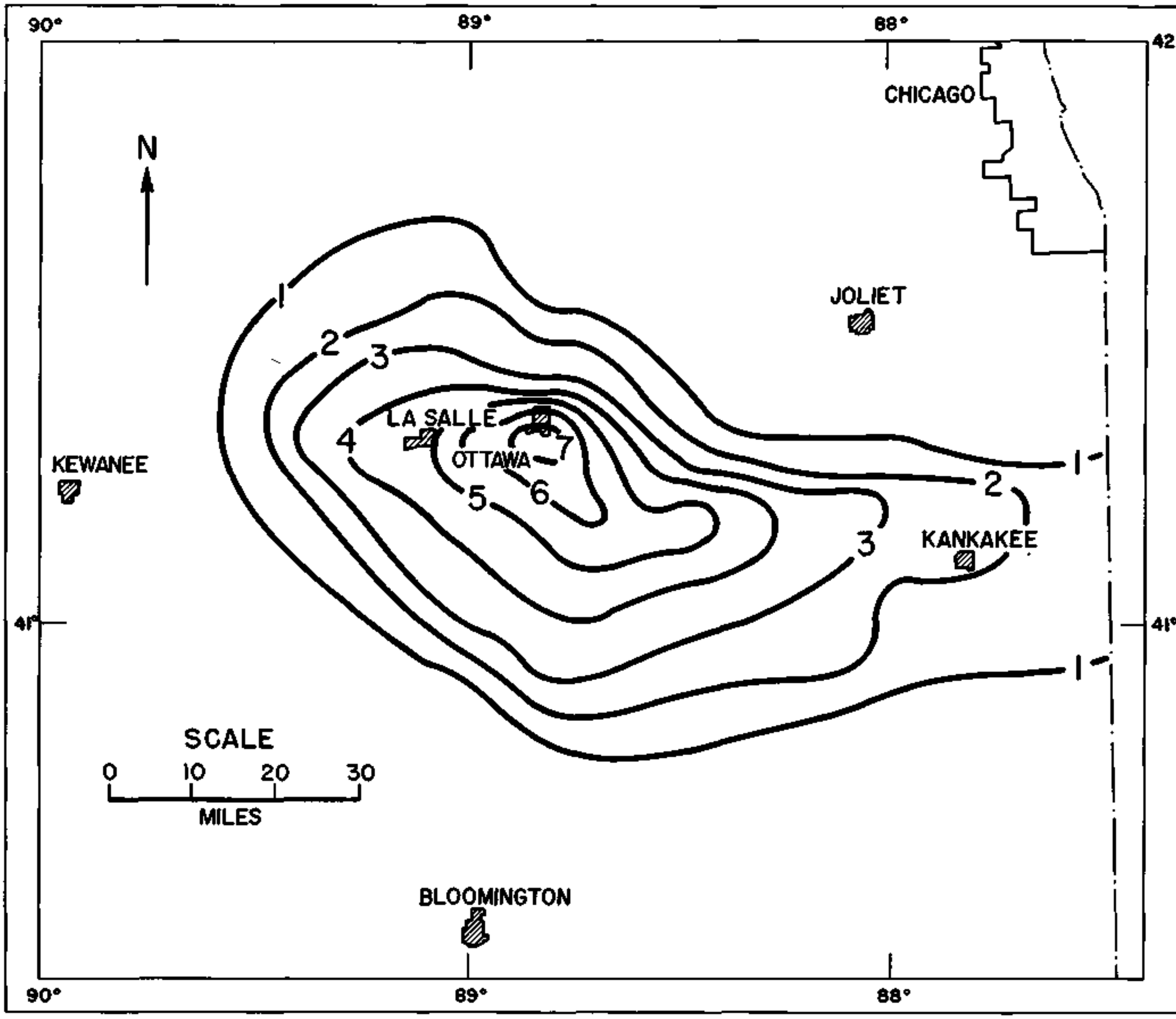


Figure 3. Maximum 6-hour rainfall for July 14, 1958

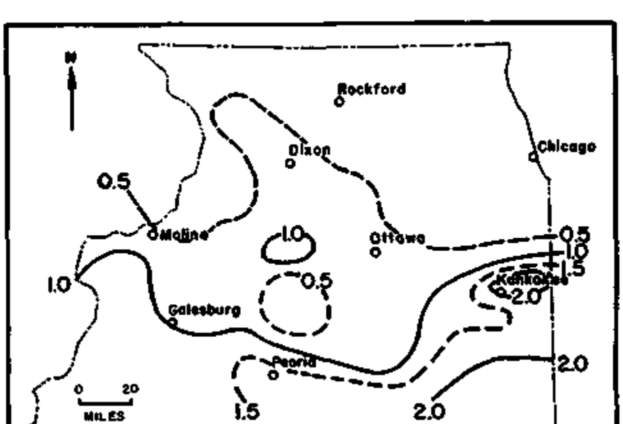


Figure 4. Total rainfall for July 9-13, 1958

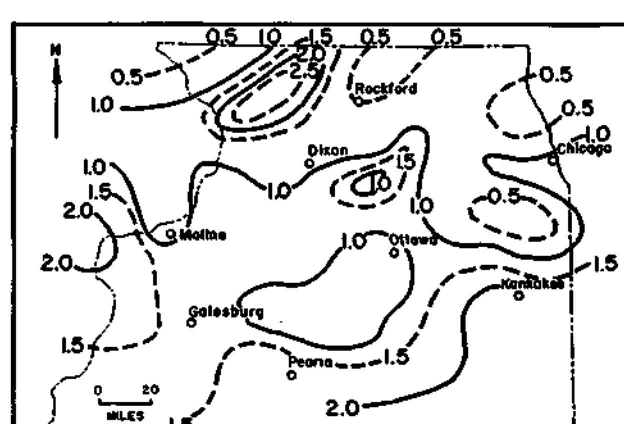


Figure 5. Total rainfall for July 4-13, 1958

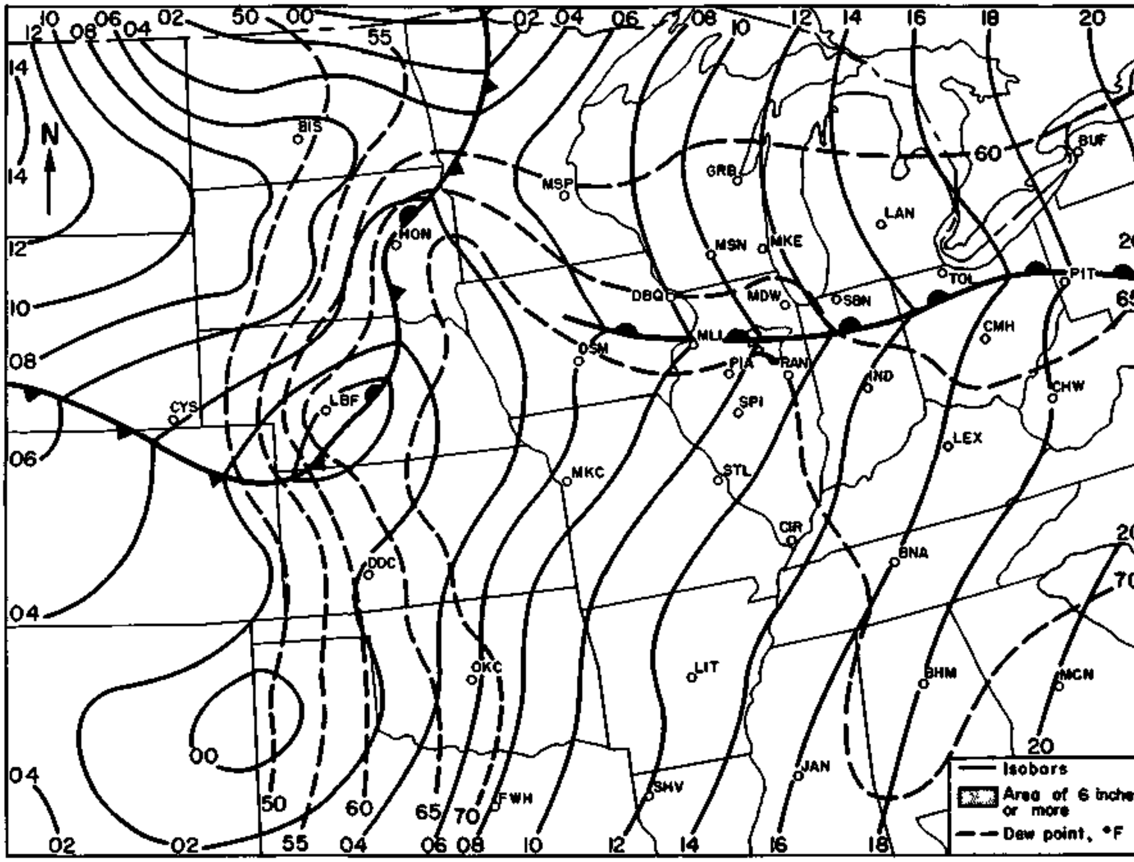


Figure 6. Surface synoptic map at 0000 CST an July 14, 1958

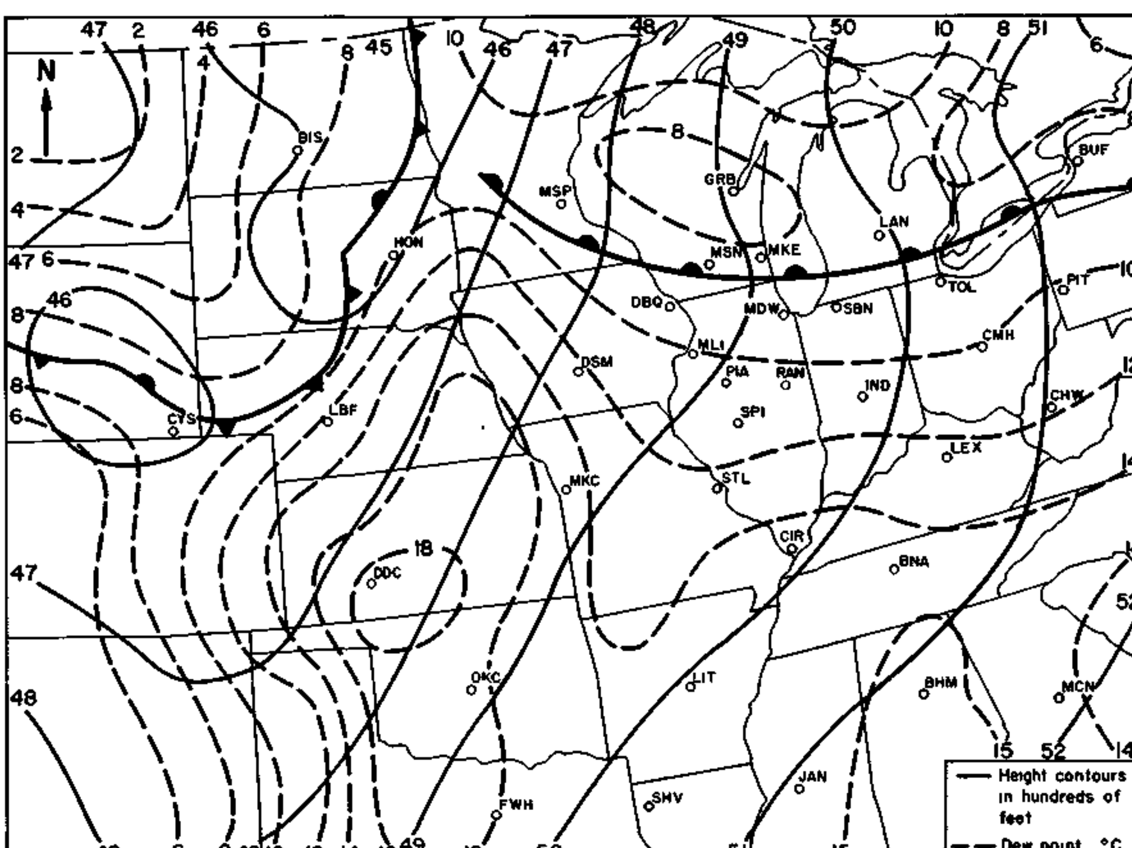


Figure 7. 850-mb map at 1800 CST on July 13, 1958

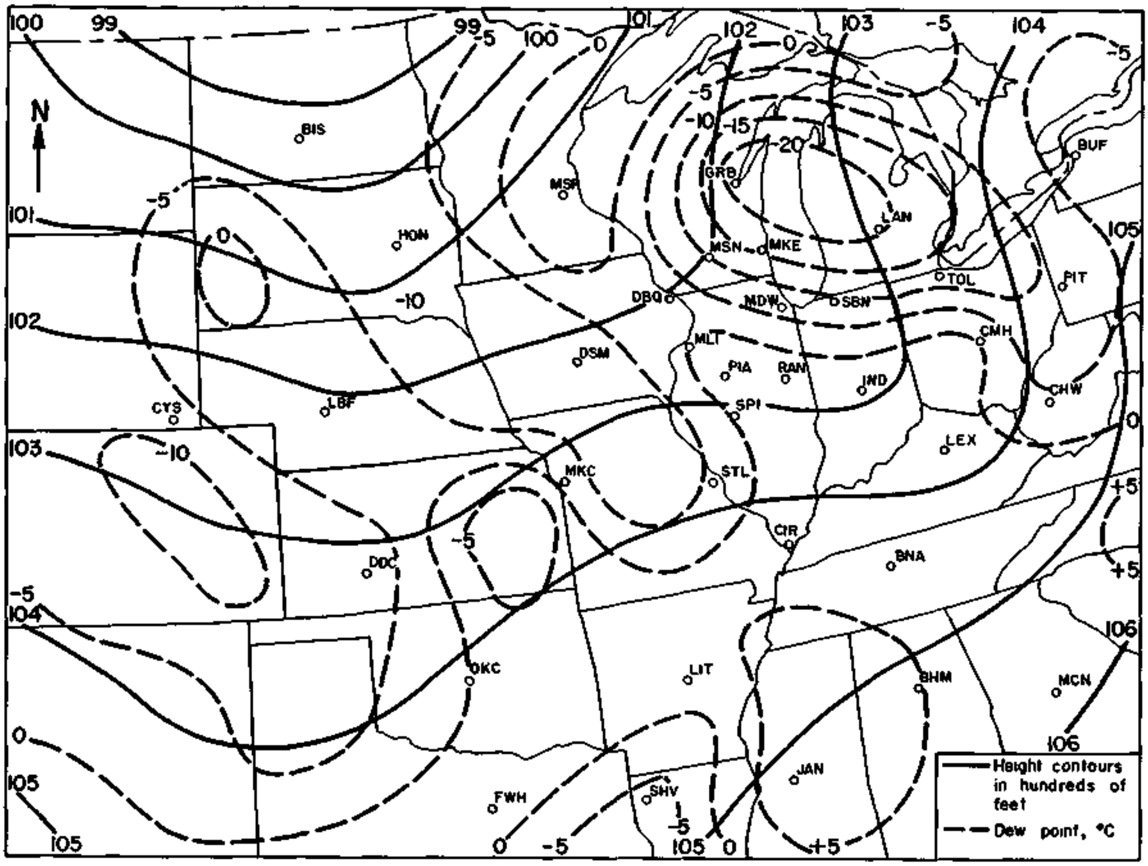


Figure 8. 700-mb map at 1800 CST on July 13, 1958

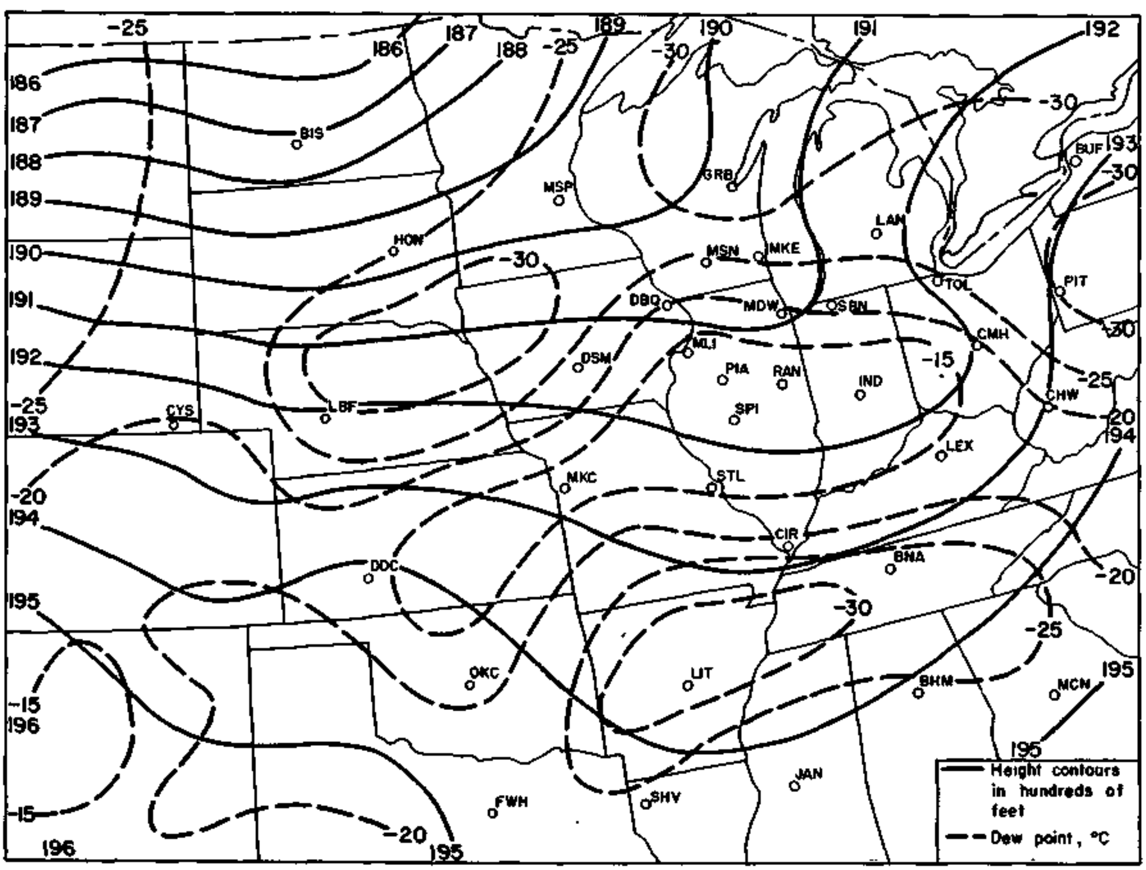


Figure 9. 500-mb map at 1800 CST on July 13, 1958

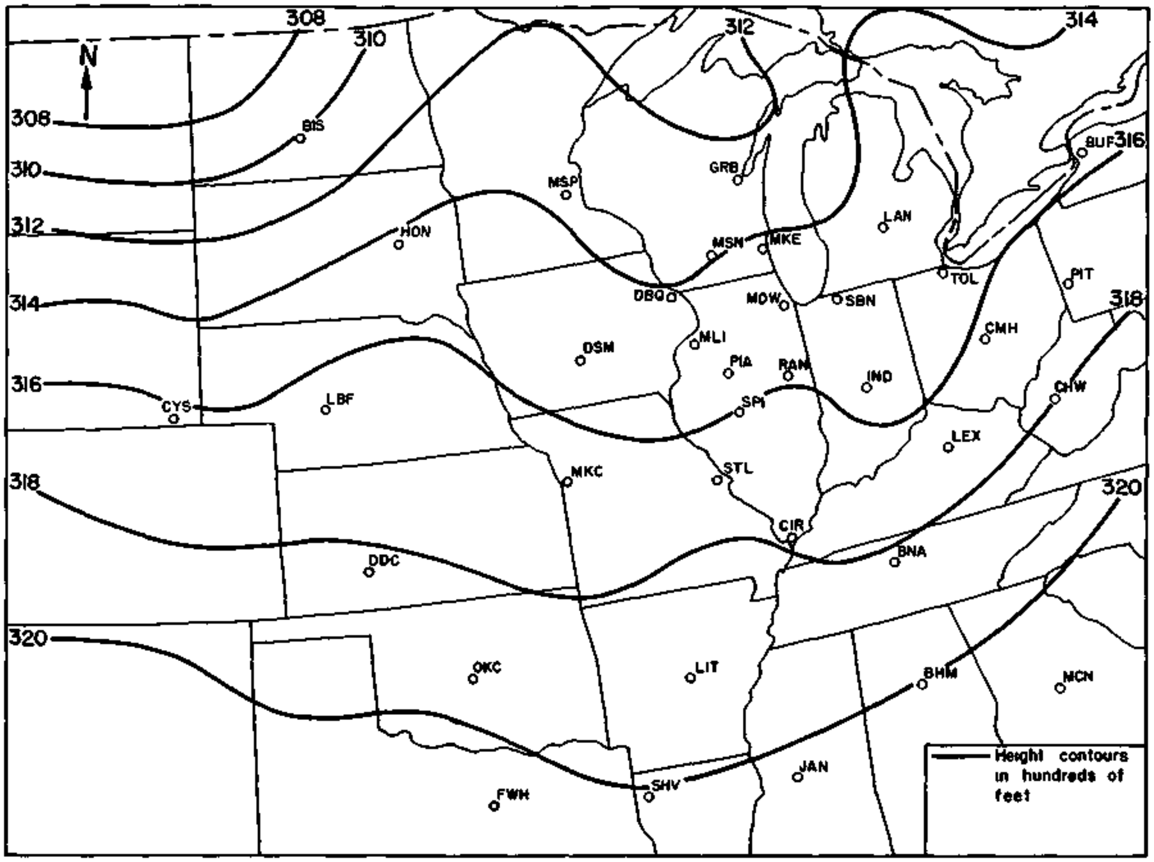


Figure 10. 300-mb map at 1800 CST on July 13, 1958

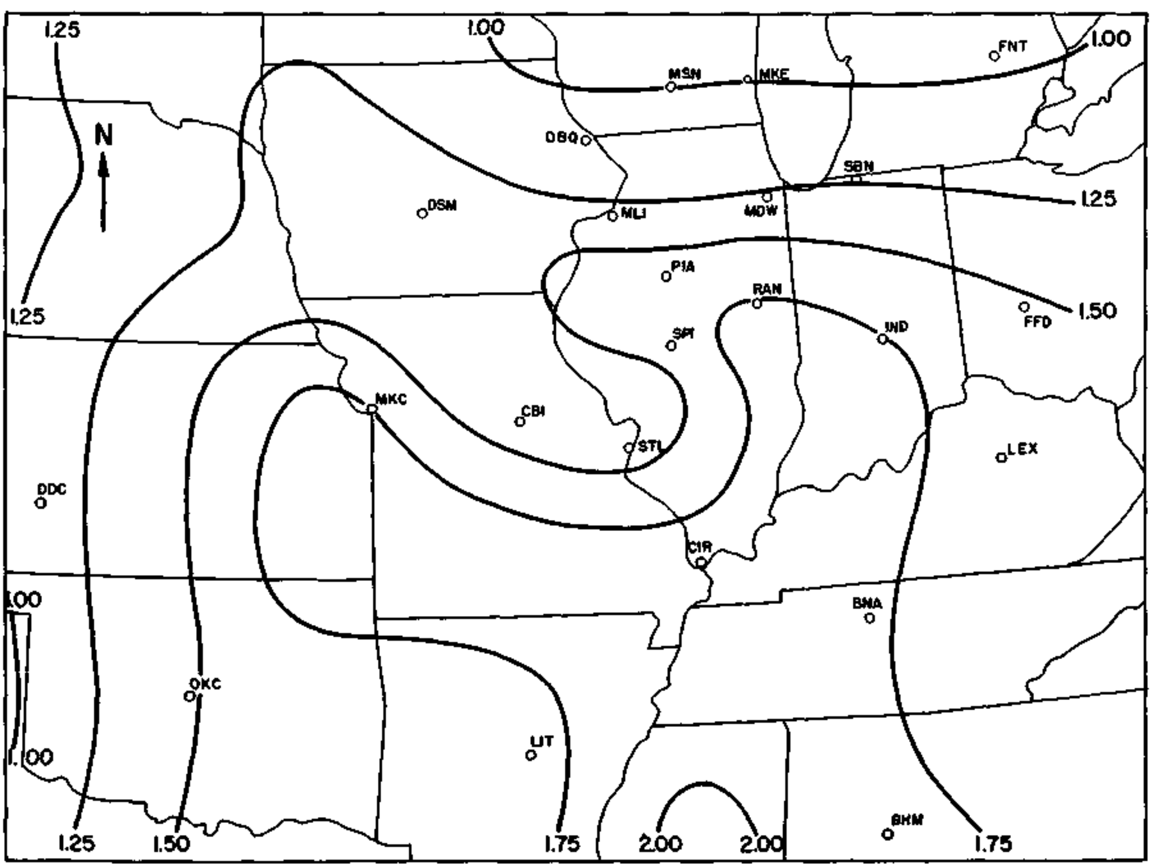


Figure 11. Precipitable water for surface to 400 mb at 1800 CST on July 13, 1958

STORM OF APRIL 26-28, 1959

On April 26-28, 1959, a rainstorm occurred in which 36-hour amounts of 4 to 6 inches were recorded in north central and northeastern Illinois. This was an unusually severe storm for this area at this time of the year. Although rainfall extended over a period of 48 hours, most of it fell within a few hours in three periods of intense rainfall. The first occurred during the late afternoon and evening of the 26th, the second during the early morning of the 27th, and the last during the late afternoon and evening of the 27th. A portion of the heaviest rainfall took place on the Panther Creek watershed in north central Illinois, where the State Water Survey operates a network of 10 recording raingages in an area of 100 square miles. Analysis of the network data indicates that measurable rainfall occurred during 18 to 24 hours of the 48-hour period which began at 1500 CST on April 26. Only light amounts were recorded during the last 12 hours of the 48-hour period.

Isohyetal Patterns

A storm isohyetal map for Illinois for the 48-hour period beginning at 1500 CST on April 26 is shown in Figure 12. The analysis is based upon observations of the climatological network of the U. S. Weather Bureau, and raingages operated by the State Water Survey, State Division of Waterways, and the U. S. Geological Survey. Figure 12 shows three centers in the overall rainfall pattern, one extending westward from the Chicago region, a second oriented WSW-ENE in the vicinity of the Panther Creek Network, and a third extending westward from the vicinity of Watseka. The heaviest amounts were recorded a few miles east of the Panther Creek Network. The storm was of great areal extent with amounts of 3 to 4 inches recorded in eastern Iowa and a belt with 3 to 5 inches extending across central Indiana, eastward from the storm center shown at Watseka in Figure 12.

Characteristics of Rainfall Distribution

Mass rainfall curves for recording gage stations located within or near the three rainfall centers of Figure 12 are shown in Figure 13, based on hourly amounts. Locations of these stations are shown in Figure 12. The curve for Gage 6 of the Panther Creek Network, associated with the heaviest of the three storm centers of Figure 12, shows three distinct periods of rainfall, the first and third being the heaviest. From 1500 to 2100 CST on April 27, 1.95 inches fell, while in the 6-hour period, 1500-2100 CST on the 26th, 1.58 inches were recorded. A 3-hour total of 1.90 inches occurred from 1500 to 1800 on the 27th and a 1-hour total of 1.20 inches from 1600 to 1700 on the same date. These are unusually heavy intensities for April rainstorms in this area. At Shabbona in the most northern rainfall center of Figure 12, a 6-hour total of 3.30 inches was recorded between 1700 and 2300 on the 27th, while Crete in the same storm center had 2.57 inches during the 6 hours beginning at 1900 on the 27th. Maximum 3-hour amounts at Shabbona and Crete were 2.50 inches and 2.32 inches, respectively. Rainfall in the third center near Watseka in Figure 12 appeared to be heaviest in the first storm period during the late afternoon and evening of the 26th. The mass curve for Piper City, on the northwest edge of the center, shows a 6-hour total of 1.44 inches from 1600 to 2200 on the 26th, with only light to moderate amounts throughout the rest of the storm period.

Depth-Duration-Area Relations

Area-depth relations for the 48-hour storm period are shown in Table 3. Since only a few hundredths of an inch fell at scattered points in the storm zone during the last 12 hours of the storm, the values for48 hours (Table 3)are nearly identical with those for 36 hours and, considering computational and sampling accuracy, may be used for both periods.

Antecedent Rainfall

Figures 14 and 15 show the total rainfall for periods of 5 and 10 days preceding the April 26-28 storm. Normal 5-day and 10-day rainfall in the storm region during the latter part of April is approximately 0.60 inch and 1.20 inches, respectively. Figure 14 shows scattered areas of above normal rainfall for the April 21-25 period, one of which is in parts of the Watseka and Panther Creek centers of Figure 12. Of the three centers in Figure 12, only the eastern part of the Watseka center is in a region experiencing above normal rainfall for the 10 days preceding the storm.

TABLE 3

DEPTH-DURATION-AREA DATA, APRIL 26-28, 1959

Period (hours)	Depth (in.) for given area (sq. mi.) 25	50	100	200	500	1000	2000	5000	10,000	20,000
48	6.15	5.95	5.80	5.60	5.20	4.85	4.40	3.70	3.10	2.45

Synoptic Weather

The surface map at 0600 CST, April 26, showed a quasi-stationary front oriented W-E across south central Illinois (Fig. 16). Wave formations were indicated along this front which extended westward through Missouri and eastward through Indiana to Ohio, where it became a cold front and extended northeastward into New England. The quasi-stationary front had passed through Illinois as a cold front on the previous day. A relatively strong flow of maritime tropical air into Illinois was indicated with temperatures near 60°F and dew points near 55°F south of the front in Illinois. Temperatures ahead of the front in northern Illinois were 45 to 50 degrees. The isobars and winds indicated strong shear across the front.

Twenty-four hours later at 0600 CST on April 27 the quasi-stationary front had drifted a few miles northward, but was still oriented W-E across central Illinois (Fig. 16). Heavy rain occurred in the region from Chicago to Moline during the evening of the 26th, and was apparently associated with a wave on the front to the south of the rain area. The main low pressure center was located in southeastern Kansas.

By 0000 CST on April 28 the Kansas low had moved northeastward to the vicinity of Peoria, Illinois, with a warm front extending eastward and a cold front southwestward out of the low center (Fig. 16). During the late afternoon and evening of the 27th heavy rainfall was recorded in the region from Peoria eastward through Illinois, associated with the approach of the low center.

By 0600 CST on the 28th (Fig. 16) the low center had moved northeastward to Lake Michigan and the cold front was moving eastward out of Illinois. Except for light amounts, the rainfall m Illinois had ended by the early morning of the 28th with the passage of the low center.

Figure 17 shows upper air charts for 1800 CST on April 26 during the first major storm of the April 26-28 period. Figure 18 shows similar charts 24 hours later during the third and final major storm of the period, and the storm in which the heaviest intensities were experienced over most of the storm zone. At 850 mb (Fig. 17) southwesterly flow of 20 to 30 knots was indicated in Illinois behind the quasi-stationary front. At 700 mb WSW-W winds at 30 to 40 knots were present, while at 500 mb westerly winds of 60 knots were indicated. The upper air data for 1800 CST, April 27 (Fig. 18), indicated southwesterly winds of 20 to 30 knots in the storm region at 850 mb. becoming WSW at 30 to 40 knots at 700 mb, WSW at 40 to 50 knots at 500 mb, and WSW at 60 to 80 knots at 300 mb.

During the storm period precipitable water values in excess of 1 inch were recorded, considerably above the normal of 0.75 inch at this time of the year. A tongue of high precipitable water extended northward from Texas and then eastward through Illinois, Indiana, and Ohio, approximately parallel to the quasi-stationary front and to the bands of heavy rainfall in northern Illinois.

The Showalter stability index indicated unstable conditions over northern Illinois during the storm period. The Peoria RAOB indicated indices of -1 to -3 during the rainfall period, while values of -4 were observed to the southwest with the main low center. The freezing level was near 11,000 feet during the storm.

Radar Analysis

The radar was not in operation during the first storm period on the 26th. Radar observations with the CPS-9 were available for the period 0730-2230 on the 27th, which included most of the second storm period. Reference to radar photographs of the PPI showed several squall lines or zones moving northward on the 27th. Early on the 27th a zone in northern Illinois was oriented NW-SE. Others which developed later were oriented WNW-ESE, becoming nearly W-E during the evening as the low center approached and passed and the heavy rainfall ended. During the late evening the radar portrayed very well the precipitation pattern associated with the low pressure system and its associated warm and cold fronts.

At 0730 CST a line was oriented NW-SE across northeastern Illinois just south of Chicago. This line appeared to intersect with another group of echoes in western Indiana. Also, at that time a second line oriented WNW-ESE appeared to develop or intensify in the vicinity of the radar station. By 1000 CST the northeastern Illinois line had dissipated to some extent, while the second line through the radar station at 0730 was well defined and about 40 miles north of the station (Fig. 19). A third line had developed and moved northward to about 40 miles south of the station. Scattered echoes were present in southwestern Illinois

By noon a fourth line was visible about 60 miles south of the station. At that time the second line was detectable about 80 miles to the northeast, while the third line had apparently dissipated. However, it appeared that this line regenerated an hour or two later to the north of the station and merged in the region of heavy rainfall with the fourth line. The fourth line moved northward at 20 to 25 knots compared to about 15 knots for the earlier lines.

By 1500 CST (Fig. 19) the merger of the third and fourth lines had been completed40 to 50 miles north of the station. The second line was located in extreme northeastern Illinois, and a fifth line which had developed to the south had moved northward to the vicinity of the radar station. By 1900 CST (Fig. 19) the series of northward-moving lines had ceased, and one large W-E squall zone was associated with the warm front which was moving northward with the approaching low center from the southwest. At that time the radar (Fig. 19) was detecting a squall line in eastern Missouri associated with the cold front out of the low center. By 2200 CST (Fig. 19) the squall lines or zones associated with the warm and cold fronts out of the low center were well defined over Illinois.

Summary

An unusually intense April rainstorm occurred over north central and northeastern Illinois on April 26-28, 1959. Amounts of 4 to 6 inches were recorded in 36 hours, while 6-hour amounts in excess of 3 inches and 3-hour amounts of 2 to 3 inches occurred in some areas. Most of the storm rainfall occurred in three distinct storms within a period of 48 hours. The first two storms were associated with a quasi-stationary front through central Illinois, while the third occurred in conjunction with warm and cold frontal activity, associated with the approach and passage of a low pressure center which formed on the quasi-stationary front in Kansas. The storm was of great areal extent with average rainfall of 2.45 inches over 20,000 square miles in Illinois. Amounts of 3 to 4 inches were recorded in eastern Iowa and a band with amounts of 3 to 5 inches extended across central Indiana.

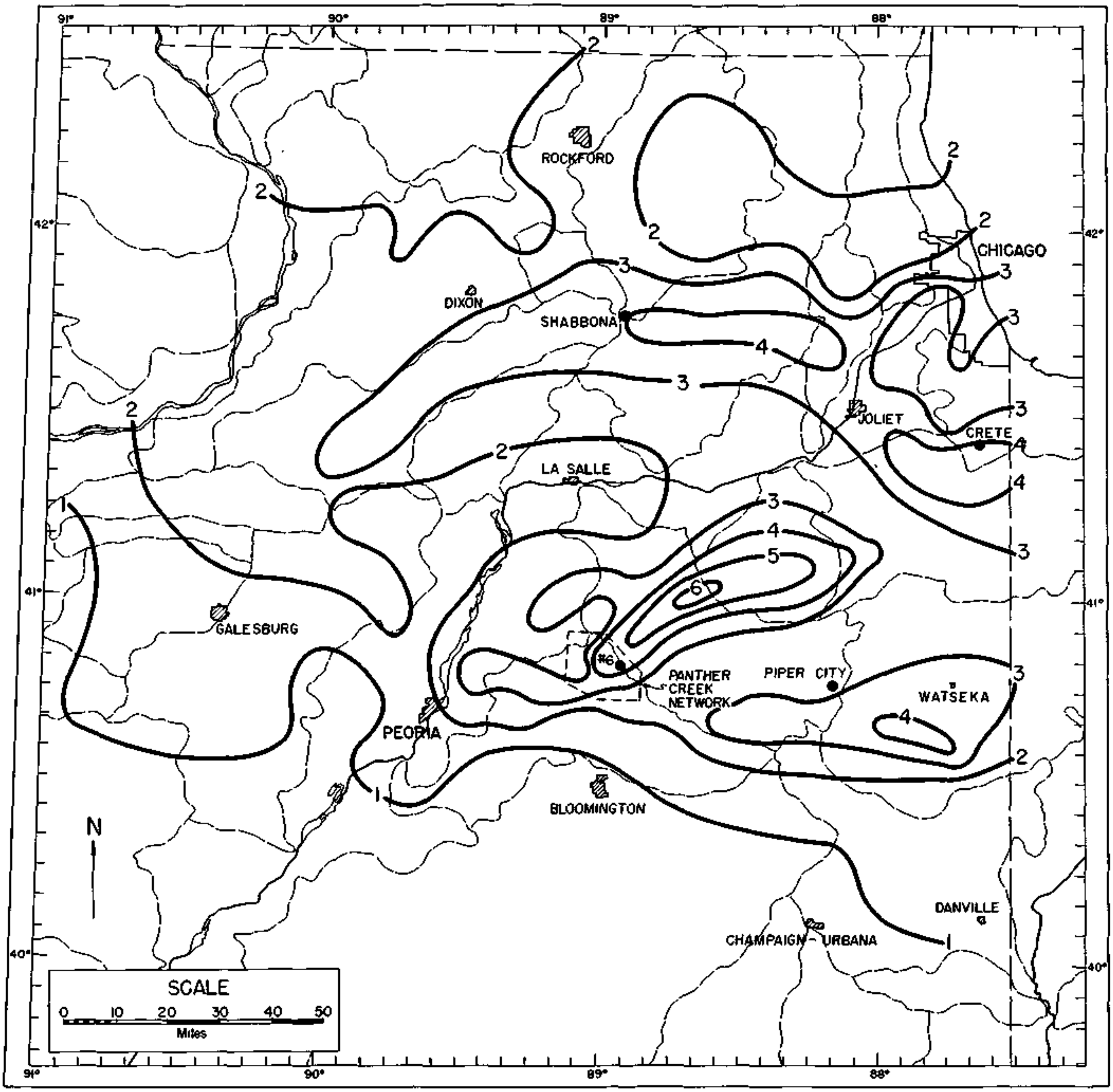


Figure 12. Total storm rainfall for April 26-28, 1959

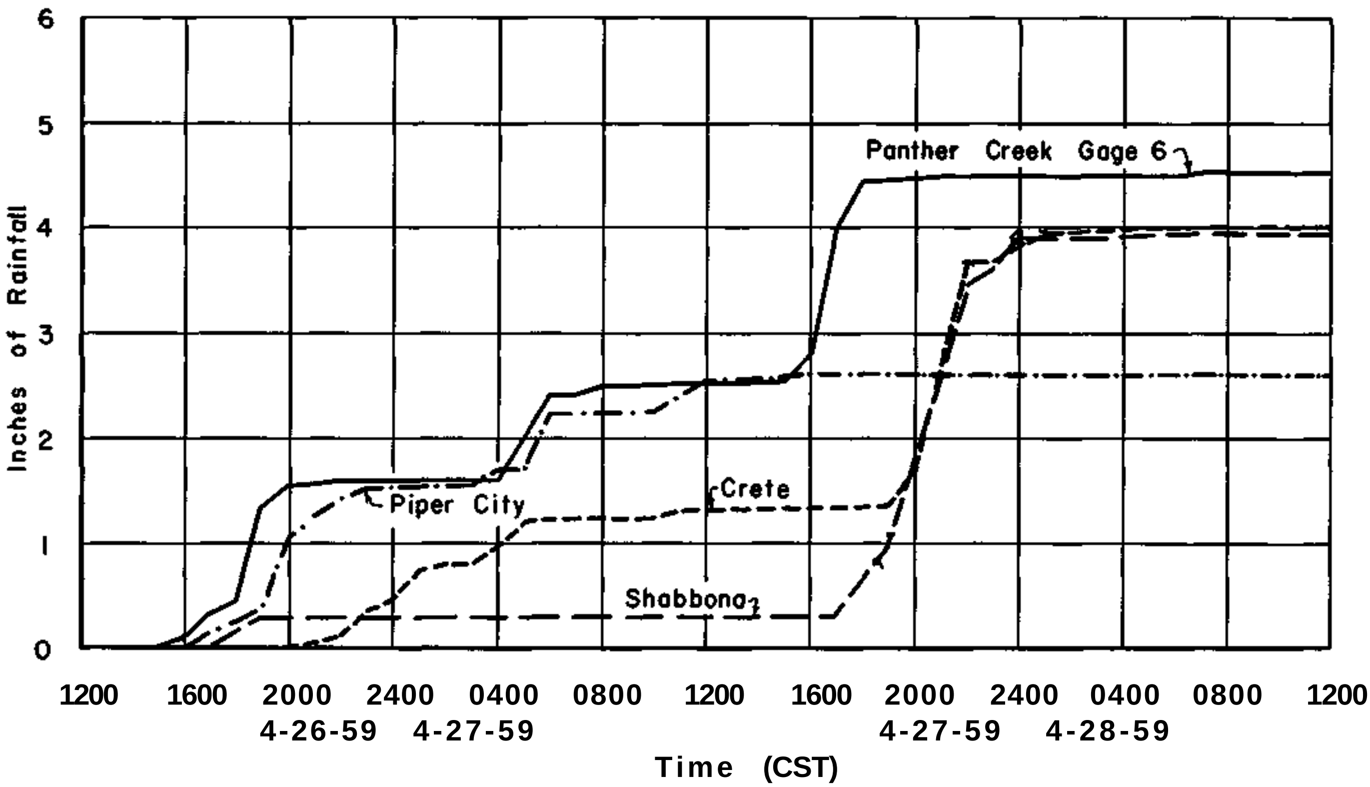


Figure 13. Mass curves of rainfall from selected stations for April 26-28, 1959

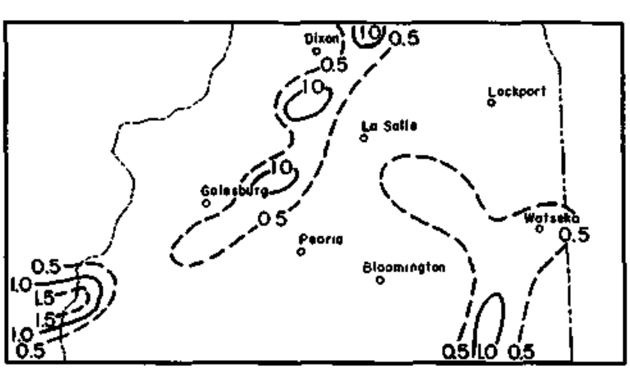


Figure 14. Total rainfall for April 21-25, 1959

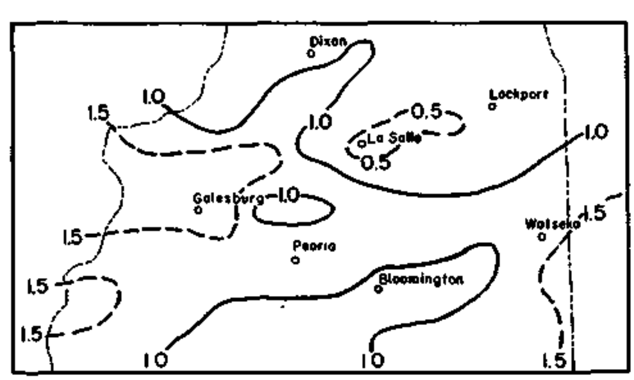


Figure 15. Total rainfall for April 16-25, 1959

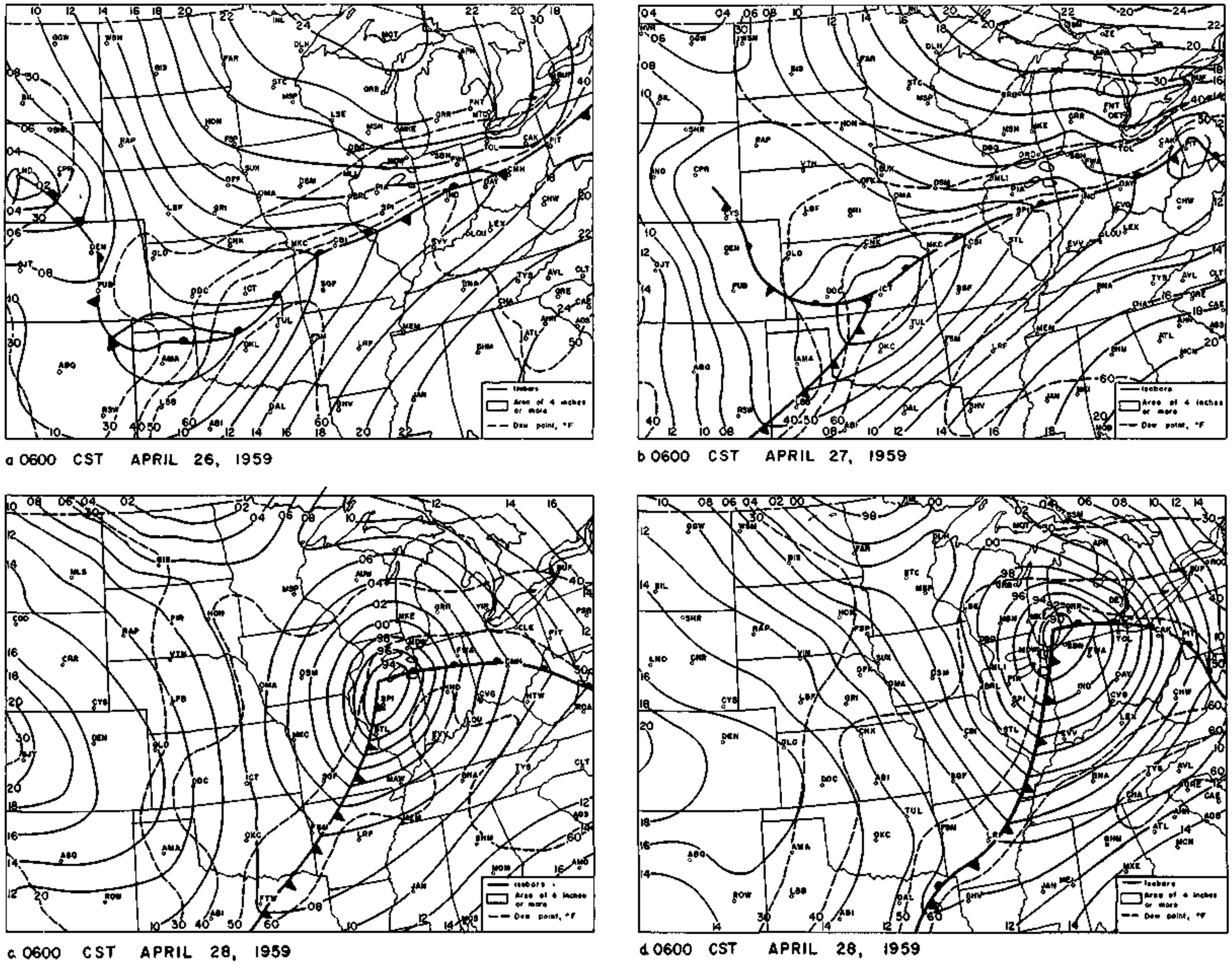


Figure 16. Surface synoptic maps for April 26-28, 1959

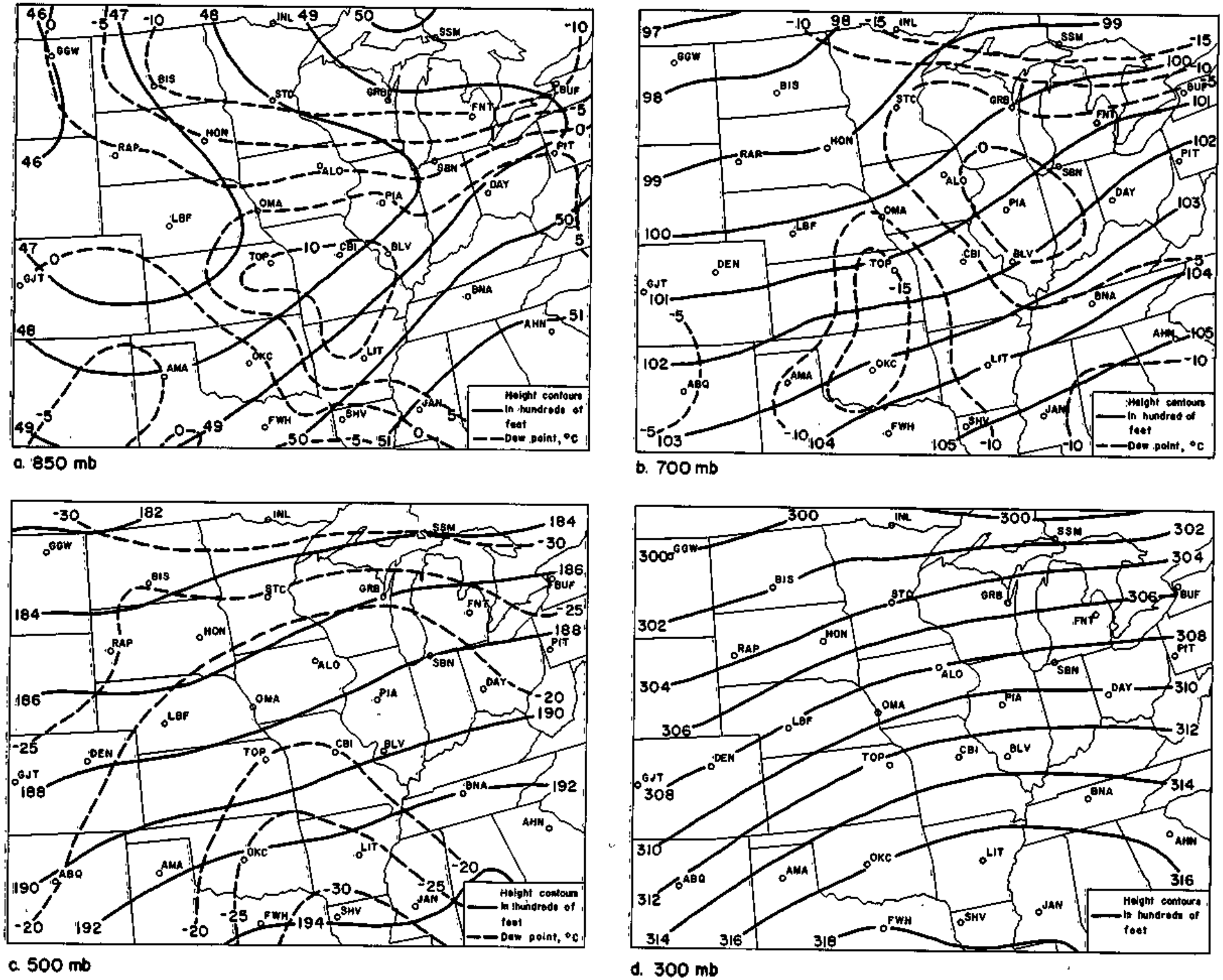


Figure 17. Upper air maps for 1800 CST, April 26, 1959

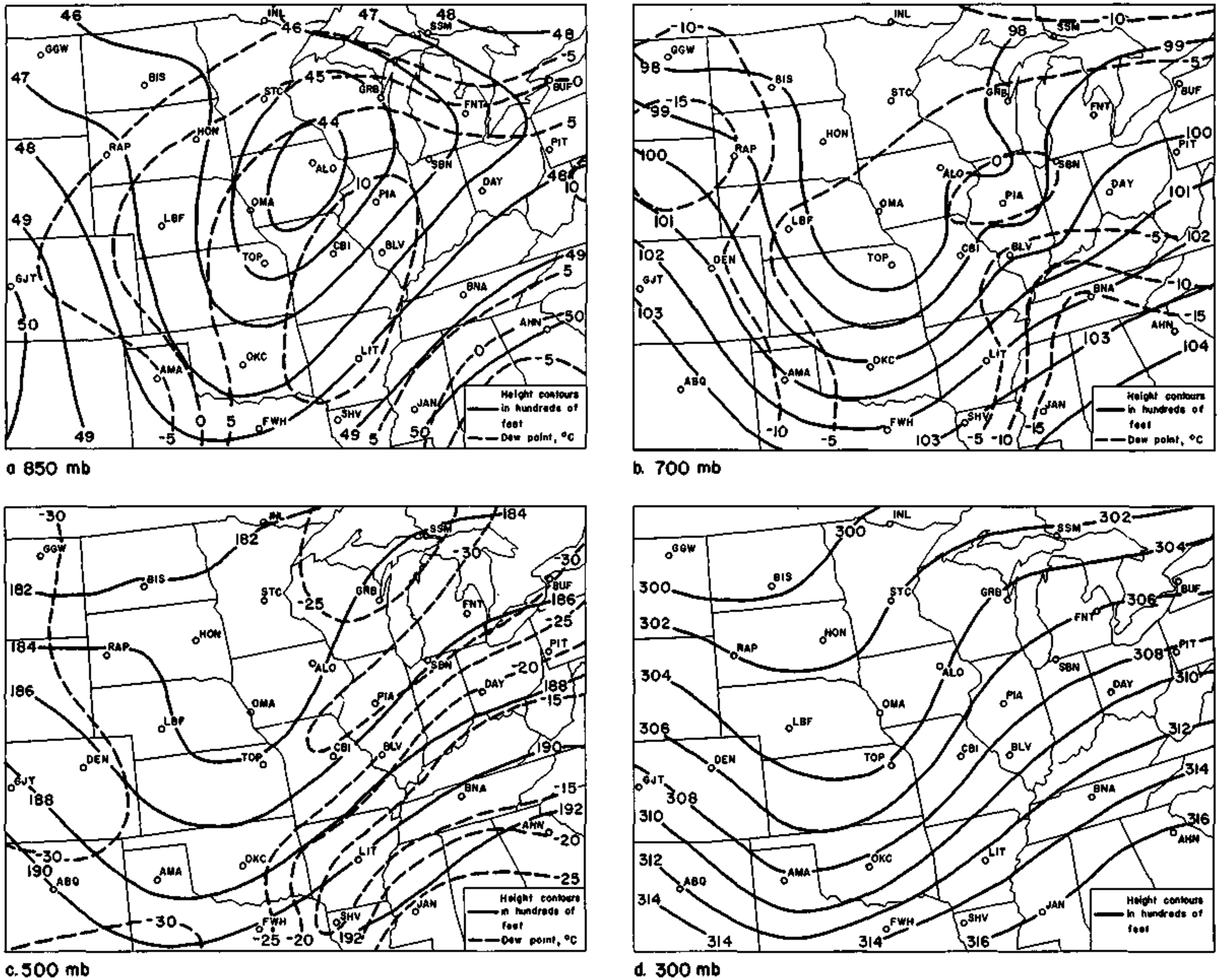


Figure 18. Upper air maps for 1800 CST, April 27, 1959

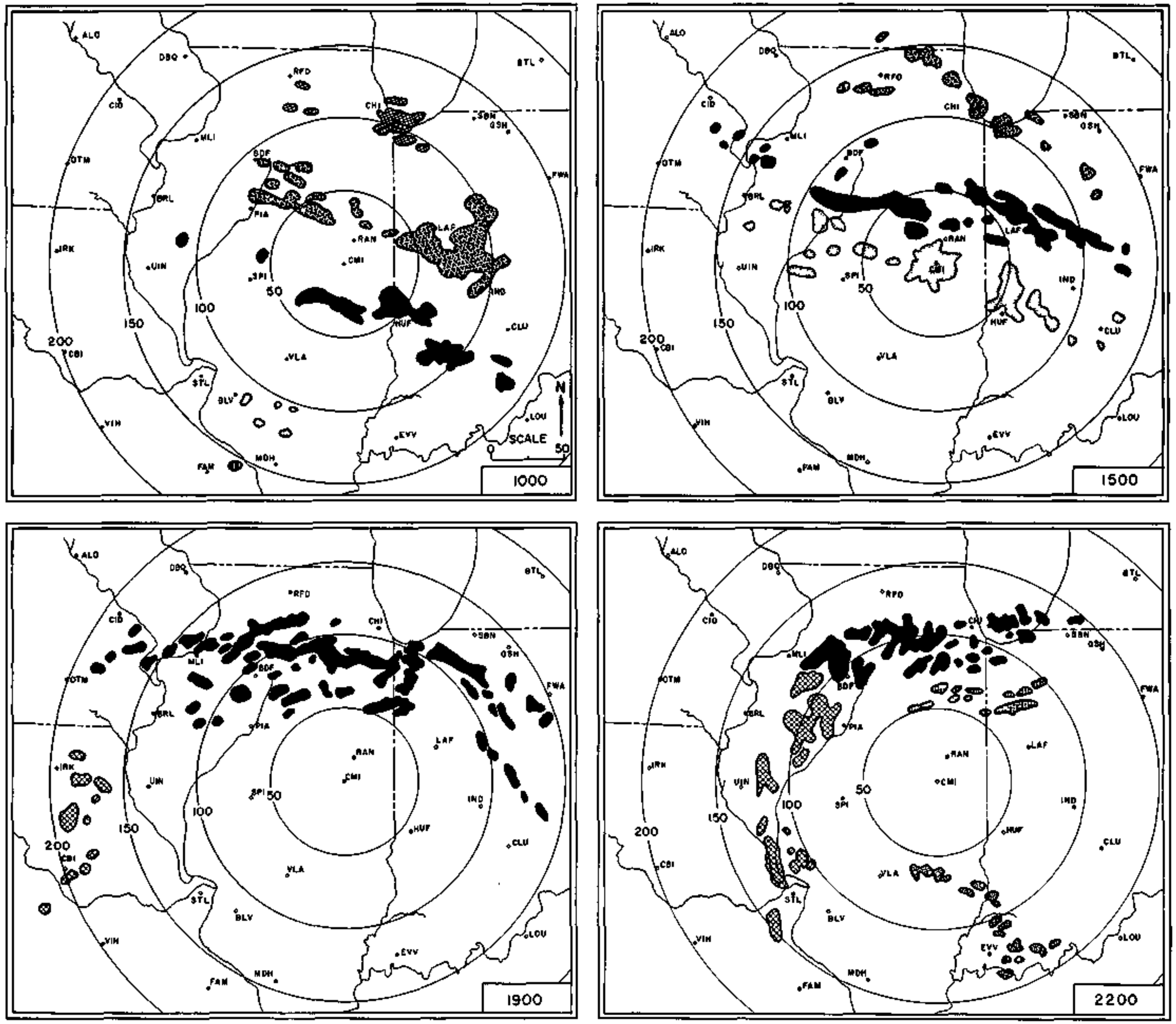


Figure 19. Radar echoes on April 27, 1959

STORM OF MAY 20-21, 1959

During the evening of May 20, 1959, a severe rainstorm occurred over portions of eastern and northeastern Illinois in which very heavy short-period amounts were recorded. Rainfall amounts which exceeded 4 inches within 3 hours were recorded at several locations along the axis of the storm. Near Kankakee in northeastern Illinois, 6-hour amounts of approximately 6 inches were observed. An area of approximately 225 square miles received 6-hour amounts in excess of 4 inches. The storm axis was oriented NNE-SSW and extended from the vicinity of Crete in northeastern Illinois to Champaign-Urbana in the east central part of the state. Lighter showers which occurred earlier on the 20th and in the early forenoon of the 21st combined with the major storm to produce 24-hour amounts exceeding 5 inches in the vicinity of Champaign-Urbana and Paxton and 7 inches near Kankakee (Fig. 20).

A detailed field survey of the storm was conducted by personnel of the State Water Survey with emphasis placed upon obtaining observations within and near the core of the storm. A total of 202 observations were obtained on this field survey. Additional data from 16 raingages operated by the Water Survey and 17 raingages operated by the U. S. Weather Bureau in the storm region provided 235 rainfall observations for defining isohyetal patterns. Radar observations of the storm provided valuable data on the storm characteristics in both the horizontal and vertical planes. A portion of the most intense region of this storm passed over an urban network of 14 raingages in Champaign-Urbana. This network, which contains 10 recording and 4 non-recording gages in a 10-square-mile area, provided unusually detailed information on the space and time distribution of rainfall over the urban area.

Isohyetal Patterns

An isohyetal map for the entire storm period is presented in Figure 20. All of the storm rainfall occurred within the 24-hour period ending at 0800 CST on May 21. Reference to Figure 20 shows three rainfall centers along the storm axis in the vicinity of Champaign-Urbana, Paxton, and Kankakee. Approximately 95 percent of the rainfall in these centers occurred during the evening storm of May 20. Figure 21 shows the total storm isohyetal pattern for Champaign-Urbana and vicinity in greater detail. Figure 22 shows the isohyetal pattern during the maximum 3-hour rainfall period in Champaign - Urbana and vicinity, while Figure 23 shows the rainfall patterns in the Champaign-Urbana urban area during the maximum 30-minute, 1-hour, 2-hour, and 3-hour rainfall periods. These approximations of the isohyetal patterns during various peak periods of the storm were obtained through use of lsopercentile maps constructed from recording gage data. The portion of the storm zone analyzed for each peak period was dictated by the recording gage density within the storm zone. The detailed analysis for the urban area of Champaign-Urbana was made possible by the network of 10 recording gages.

Probability Analysis

To further evaluate the intensity and variability in the storm of May 20, the maps in Figures 24 and 25 were prepared. Figure 24 shows the average recurrence interval of the maximum 3-hour rainfall amounts observed in Champaign-Urbana and vicinity. The lines on this map connect points having equal recurrence intervals, based upon published rainfall frequency relations.[6] Thus, the 50-year line connects points whose 3-hour rainfall was of the magnitude to be expected once in 50 years at these points; therefore, the 50-year line also encloses the area which experienced rainfall amounts that should not be exceeded more than once in an average 50-year period. Figure 25 was prepared in the same manner, and shows relations in the Champaign-Urbana urban area, based upon maximum rainfall amounts recorded during periods of 30 minutes to 3 hours in the storm. Referring to Figure 25, it is seen that 3-hour amounts equalling or exceeding those to be expected once in 100 years were recorded in west Champaign, while in east Urbana amounts dropped below the 1-year expectancy. Amounts exceeding 4 inches within 3 hours were recorded in west Champaign during the evening of May 20, while less than an inch was recorded on the east side of Urbana, 3 to 4 miles from the Champaign storm center(Fig. 23). Although the relative intensity and spatial variability were considerably less for the 30-minute and 1-hour maximum amounts than for the 2-hour and 3-hour values (Fig. 25), the variation was still quite great for these periods with values of recurrence interval ranging from 25 and 50 years to less than 1 year. Table 4 shows the percent of the 10-square-mile urban area experiencing rainfall amounts equalling or exceeding various recurrence-interval values for durations of 30 minutes to 24 hours. For example, 16 percent or 1.6 square miles of the total urban area received 3-hour rainfall amounts equalling or exceeding the amount to be expected on an average of once in 50 years. The 6-inch amounts which fell in 6 hours in the Kankakee region exceed the 100-year frequency of point rainfall in this region. Three-hour amounts of approximately 4 inches which occurred in the Kankakee region correspond to 75- to 100-year expectancies.

Table 5 shows the amount of area in the entire storm zone which experienced 6-hour and 24-hour rainfall that equalled or exceeded values expected for various recurrence intervals.

TABLE 4

RECURRENCE INTERVAL OF RAINFALL AMOUNTS OCCURRING
IN URBAN AREA, MAY 20-21, 1959

Recurrence Interval (years)	Percent of 10-sq.-mi. area experiencing given frequency values for various durations						
	0.5-hr.	1-hr.	2-hr.	3-hr.	6-hr.	12-hr.	24-hr.
2	47	70	77	77	71	67	56
5	20	55	64	61	54	46	30
10	6	36	51	46	39	25	11
25	0	16	33	29	19	0	0
50	0	0	11	16	0	0	0
100	0	0	3	5	0	0	0

TABLE 5

RECURRENCE INTERVAL OF MAXIMUM RAINFALL AMOUNTS,
ENTIRE STORM ZONE, MAY 20-21, 1959

Duration (hours)	Area (sq. mi.) with rainfall equalling or exceeding given recurrence-interval value (yrs.)					
	2	5	10	25	50	100
6	1050	720	500	280	135	60
24	830	450	240	75	30	--

Characteristics of Rainfall Distribution

Mass rainfall curves constructed from recording gage stations along or near the core of the storm are shown in Figure 26. Station locations are shown in Figures 20 and 21. These mass curves show the typical characteristics of the thunderstorm or flash flood rains, consisting of a number of bursts or individual showers during the total storm period. The most showers and the longest period of rainfall are indicated by the Kankakee curve with five distinct bursts between 1600 and 2200 CST, and this curve is representative of the region in which total storm rainfall was greatest. In the Champaign storm center, three-distinct bursts are indicated between 1700 and 2100 CST, while two bursts are indicated by the other two curves which represent areas with less total storm rainfall.

Depth-Duration-Area Relations

Tables 6-8 show area-depth relations for the total storm period and for peak periods of 30 minutes to 12 hours within various regions of the storm. As indicated earlier, the regions within which satisfactory estimates could be made for incremental periods of the storm were dictated by the recording gage density.

TABLE 6

DEPTH-DURATION-AREA DATA,
URBAN AREA, MAY 20-21, 1959

Duration (hours)	Depth (in.) for given area (sq. mi.)										
	0.1	0.2	0.5	1.0	1.5	2.0	3.0	4.0	6.0	8.0	10.0
0.5	1.78	1.74	1.66	1.57	1.50	1.44	1.35	1.26	1.12	1.01	0.91
1.0	3.08	3.02	2.89	2.75	2.64	2.55	2.40	2.27	2.05	1.87	1.69
2.0	4.25	4.16	3.98	3.77	3.62	3.48	3.25	3.05	2.74	2.47	2.22
3.0	4.66	4.55	4.35	4.13	3.97	3.76	3.57	3.36	3.00	2.72	2.45
6.0	4.67	4.57	4.38	4.17	4.02	3.84	3.65	3.45	3.11	2.85	2.60
12.0	4.72	4.63	4.45	4.25	4.10	3.92	3.75	3.55	3.23	2.98	2.75
24.0	4.88	4.81	4.62	4.41	4.26	4.07	3.91	3.69	3.37	3.10	2.87

TABLE 7

DEPTH-DURATION-AREA DATA, CHAMPAIGN-URBANA AND VICINITY, MAY 20-21, 1959

Duration (hours)	Depth (in.) for given area (sq. mi.) 1	2	5	10	25	50	100	150	200
3	4.82	4.72	4.55	4.38	4.00	3.58	2.99	2.52	2.15
6	4.89	4.79	4.61	4.45	4.09	3.67	3.09	2.63	2.30
24	5.42	5.26	4.98	4.70	4.23	3.75	3.15	2.73	2 40

TABLE 8

DEPTH-DURATION-AREA DATA, ENTIRE STORM ZONE, MAY 20-21, 1959

Duration (hours)	Depth (in.) for given area (sq. mi.) 10	25	50	100	200	500	1000	1500	2000
6	7.0	6.6	6.1	5.6	5.0	4.0	3.2	2.7	2.3
24	7.2	6.8	6.3	5.8	5.3	4.3	3.4	2.9	2.6

Antecedent Rainfall

Total rainfall for the 5-day and 10-day periods prior to the May 20 storm are indicated on the isohyetal maps of Figures 27 and 28. Normal 5-day and 10-day amounts in this region are approximately 0.65 inch and 1.30 inches, respectively. Figure 27 shows below normal amounts in the region from Champaign-Urbana to Kankakee for the 5 days prior to the storm with near normal amounts north of Kankakee. Amounts for 10 days preceding the storm were somewhat above normal in the Champaign-Urbana region, near normal in the Kankakee area, and below normal for a considerable portion of the area between Kankakee and Champaign-Urbana, along the storm axis.

Synoptic Weather

The surface synoptic weather map for 1800 CST on May 20, near the start of the storm, indicated a relatively strong flow of moist, maritime tropical air into Illinois (Fig. 29). A quasi-stationary front extended westward across central Wisconsin, then southwestward through northwestern Iowa, southeastern Nebraska, and central Kansas to a wave in northeastern New Mexico. Dew point temperatures ranged from near 70°F in eastern Illinois, where the severe rainstorm occurred, to approximately 60°F in the extreme northwestern part of the state. Air temperatures were in the low 70's in the eastern Illinois storm zone at 1800 CST, while in areas of less cloudiness to the south and west they increased to 75 to 80 degrees. Air and dew point temperatures indicated nearly saturated conditions at the surface in the storm zone with relative humidity exceeding 90 percent just prior to the start of the storm, while a few miles to the west and northwest relatively dry air existed with relative humidity of approximately 65 to 70 percent. A slight inverted trough is evident in the isobaric pattern in the storm region of eastern Illinois in Figure 29, indicative of convergence in this area.

The 850-mb chart for 1800 CST on May 20 indicated southerly flow of maritime tropical air into Illinois and a trough region centered over the eastern and central parts of the state (Fig. 30). The southerly flow was about 15 knots compared to 20 to 30 knots 12 hours earlier. A flat dew point ridge existed over the Midwest with values near 10°C in the storm region. Not much change had occurred during the previous 12 hours.

The 700-mb chart showed a trough over eastern Illinois at 1800 CST (Fig. 31). The storm region was within a dew point ridge with a relatively rapid decrease over the state to the west of the trough, which indicates a separation of relatively moist and dry air on a N-S line through Illinois, often referred to as a dew point front. The dew point front had persisted with little movement in the preceding 12 hours, but the trough was not apparent on the map for 0600 CST. Twelve hours later (0600 CST/May 21) the trough and dew point front had moved eastward to central Indiana. The trough area in Figure 31 also was an area of slightly lower temperatures than the surrounding region, and contained air near saturation and much more humid than the air to the west. Wind speeds were 15 to 20 knots immediately to the rear of the trough and 20 to 25 knots in advance of it.

At the 500-mb level (Fig. 32) a trough extended southward through eastern Illinois. The storm region was in an area of relatively strong dew point gradient and was lying west of a dew point ridge centered near the Indiana-Ohio border. Little variation in air temperature existed across Illinois, values ranging from about -10°C in the eastern to -12°C in the western part of the state. Wind speeds were 10 to 20 knots west of the trough and 20 to 30 knots east of it in the Illinois region.

The 300-mb chart indicated southwesterly flow over Illinois (Fig. 33). Wind speeds were 20 to 30 knots. Divergence was indicated over the northern part of the state at this level. There was no evidence of a jet stream in the Illinois region.

Winds aloft maps for 1200 CST on May 20, a few hours prior to the eastern Illinois storm, indicated a trough oriented approximately N-S through extreme eastern Iowa at the 5000-foot level. This trough apparently corresponded with a squall line which moved eastward through northern Illinois during the afternoon and was instrumental in producing the heavy rainfall in the Kankakee area (Fig. 20). Troughs were discernible at 10,000 feet and 18,000 feet over eastern Illinois, and their location and orientation corresponded closely with a nearly stationary squall zone which persisted over eastern and northeastern Illinois and western Indiana during the afternoon and evening, according to the CPS-9 radar display. These troughs remained nearly stationary from noon to 1800 CST, and are the same ones described earlier in the discussion of conditions at 700 mb and 500 mb The heavy rainstorms during the late afternoon and evening in eastern Illinois occurred in this squall zone, but in a region within the zone where little rainfall had occurred previously.

The precipitable water map for the layer from the surface to 400 mb is shown for 1800 CST on the 20th in Figure 34. Approximately 1.7 to 1.8 inches of precipitable water are indicated over eastern Illinois at that time. Normal precipitable water in the storm region on May 20 is approximately 1 inch. Strong advection of moisture from the south and southeast had occurred during the day. The storm region was lying on the northwest side and near the core of precipitable water. Rapid decrease in precipitable water occurred to the northwest of the core.

The Showalter stability index was approximately +3 in eastern Illinois and western Indiana at the start of the heavy storm. Twelve hours before the storm, RAOB data indicated an index of 0. At 0600 CST on the 21st it was +3.

<u>Radar Analysis</u>

At 0730 CST, May 20, the CPS-9 radar showed echo activity extending approximately 200 miles southward from the radar station. The echo mass consisted essentially of a series of bands oriented approximately W-E. As the forenoon progressed, these bands moved northward and rotated counterclockwise to some extent. This rotation produced a spiral band arrangement of the echoes. As the bands passed the station, they extended from 25 to 50 miles west to 150 to 200 miles east, a length of approximately 200 miles. The movement of one of the bands past the radar station is illustrated in Figure 35 at 0857 CST. The next band to the south is not displayed accurately due to precipitation attenuation at the station at that time associated with the passage of the other band. An earlier band, also affected by attenuation, can be seen to the north of the station oriented ENE-WSW in the LAF-RAN region. The movement of the bands was in general agreement with the flow pattern at the 700-mb and 500-mb levels at that time. The counterclockwise motion of the bands was induced apparently by the more rapid movement of the eastern portion of the bands, which were under the influence of winds approximately 10 knots stronger than those steering the western portion of the bands at the upper levels.

Light showers occurred with the bands as they passed the radar station. The echoes appeared relatively weak on the CPS-9 scope display, and tops of only 15,000 to 20,000 feet were indicated by a vertical scanning TPS-10 radar. The bands appeared to dissipate as they reached northeastern Illinois, and by noon the bands were no longer identifiable on the radar.

A squall line or zone which exhibited little movement was observed over eastern Iowa throughout the forenoon of May 20 by the CPS-9. About 1300 CST this line (Fig. 35) started moving eastward at a speed of approximately 25 knots. About noon, after the northward-moving bands had apparently dissipated, the development of an instability zone was indicated over eastern Illinois and western Indiana by echo activity portrayed on the CPS-9. This zone, which was oriented NNE-SSW, is shown in Figure 35 at 1303 CST. As the afternoon progressed, lines and groups of echoes appeared to develop in this instability zone, moving eastward and northeastward across Indiana. The heaviest rainfall prior to the Illinois storm occurred over western Indiana as showers moved out of the development zone The original instability zone, located on a line from Chicago to Vandalia, was the region within which the severe rainstorms took place during the early evening. Figure 35 at 1703 shows by different shading of the echoes the original instability zone, an area of echoes over southwestern to central Indiana, which moved out of the original instability zone; and the Iowa squall line, discussed earlier, moving toward the eastern Illinois instability zone.

The storm in the Champaign-Urbana region, which produced amounts in excess of 4 inches in less than 3 hours at its center, appeared to develop in the instability zone about 10 to 15 miles south of its eventual maximization area and moved NNE, according to CPS-9 observations. During most of the heavy rainfall period in the Champaign area, severe precipitation attenuation prevented radar observation of the storm behavior. Radar measurements of echo tops, during a short lull in the storm when attenuation of the radar beam was not severe, indicated echo tops had reached the 40,000-foot level in "the Champaign area.

Maximum storm amounts were recorded in the Kankakee region which experienced two heavy storm periods. Radar observations indicated the second period, which began about 2030 CST, was associated with a squall line which moved into the original instability zone from the west and intensified when the merger took place. This squall line was the same one discussed earlier and shown in Figure 35 at 1303 and 1703 as it moved eastward from Iowa through northern Illinois. Figure 35 at 2100 CST shows the CPS-9 presentation after the squall line had moved into the original instability zone. Elsewhere at this time, the storm appeared to be dissipating as the areal extent of radar echoes was decreasing.

The original instability zone was still in existence on a line from Chicago to Champaign when radar operations were suspended at 2115 CST. When operations were resumed at 0730 CST the next day, the instability zone was no longer in existence along its original line, but a squall line was present over eastern Indiana. This squall line appeared to be associated with the quasi-stationary trough aloft of the previous day which had moved to central Indiana by 0600 CST according to RAOB observations. Hourly rainfall during the latter part of the night was too light and scattered to portray accurately the squall line movement during this period.

Rainfall-Runoff Relations

A recording streamgage is operated by the U. S. Geological Survey which measures runoff from the Boneyard Creek watershed in Champaign near the center of the Champaign-Urbana urban area (Fig. 21). The area of the drainage basin shown in Fig. 21 is 4.64 square miles. Approximately 38 percent of this area has impervious surfaces.

An approximation of the amount of the May 20-21 storm rainfall discharged as streamflow at this streamgage was computed from the discharge recorded in the May 20-27 period. The creek discharge closely approximated base flow by May 27. This computation revealed that the amount of storm runoff was equivalent to an average depth of 1.80 inches of water over the 4.64-square-mile area. The average storm rainfall depth for this same area was 3.33 inches. Therefore, 54 percent of the storm rainfall was discharged as runoff. One light rainshower occurred in the period after the storm and before the 28th, but the resulting rainfall had no appreciable effect on the calculations of the May 20-21 storm runoff.

The hydrograph for the creek is shown in Figure 36. The storm runoff was quite rapid as the peak daily discharge occurred on the 20th. This indicated the maximum runoff occurred during and within the 2 hours after the heavy rainfall ended. The greatest instantaneous discharge from the storm was 440 second-feet which occurred at 2000 CST, May 20. Thirty-three percent of the total storm runoff was discharged by midnight on May 20, and by 2400 CST on May 22, 82 percent of the storm runoff had been discharged.

Summary

During the evening of May 20, 1959, a severe rainstorm occurred over eastern and northeastern Illinois in which 2-hour to 6-hour amounts exceeding the 100-year frequency of point rainfall were recorded at several locations along the storm axis, while amounts exceeding 25-year expectancies were observed for 30-minute to 2-hour periods. Unusually detailed information on the space and time distribution of rainfall over an urban area was provided by a network of 10 recording raingages in Champaign-Urbana, which encompasses 10 square miles and was lying along the storm axis. Extreme variability was found within the urban area, with amounts equivalent to 100-year expectancies for 2-hour to 3-hour periods dropping to below 1-year frequencies within 3 to 4 miles.

The storm developed in a quasi-stationary instability zone supported by an upper-level trough and an inflow of abnormally moist air. The severe rainstorm appeared to be aided in its development by diurnal heating, since it initiated shortly after the period of maximum solar heating. The storm region also corresponded closely with a 700-mb dew point front. The storm occurred near the boundary separating a cloudy, humid, and rainy area from a less cloudy, hotter, and less humid region to the west, with little or no rainfall, a separation which has been noted frequently in other severe rainstorms in Illinois. The region of heaviest rainfall near Kankakee was the result of the merger of a squall line moving from the west with the quasi-stationary instability zone in eastern Illinois during late evening. After this merger, the entire storm system moved eastward and decreased in intensity.

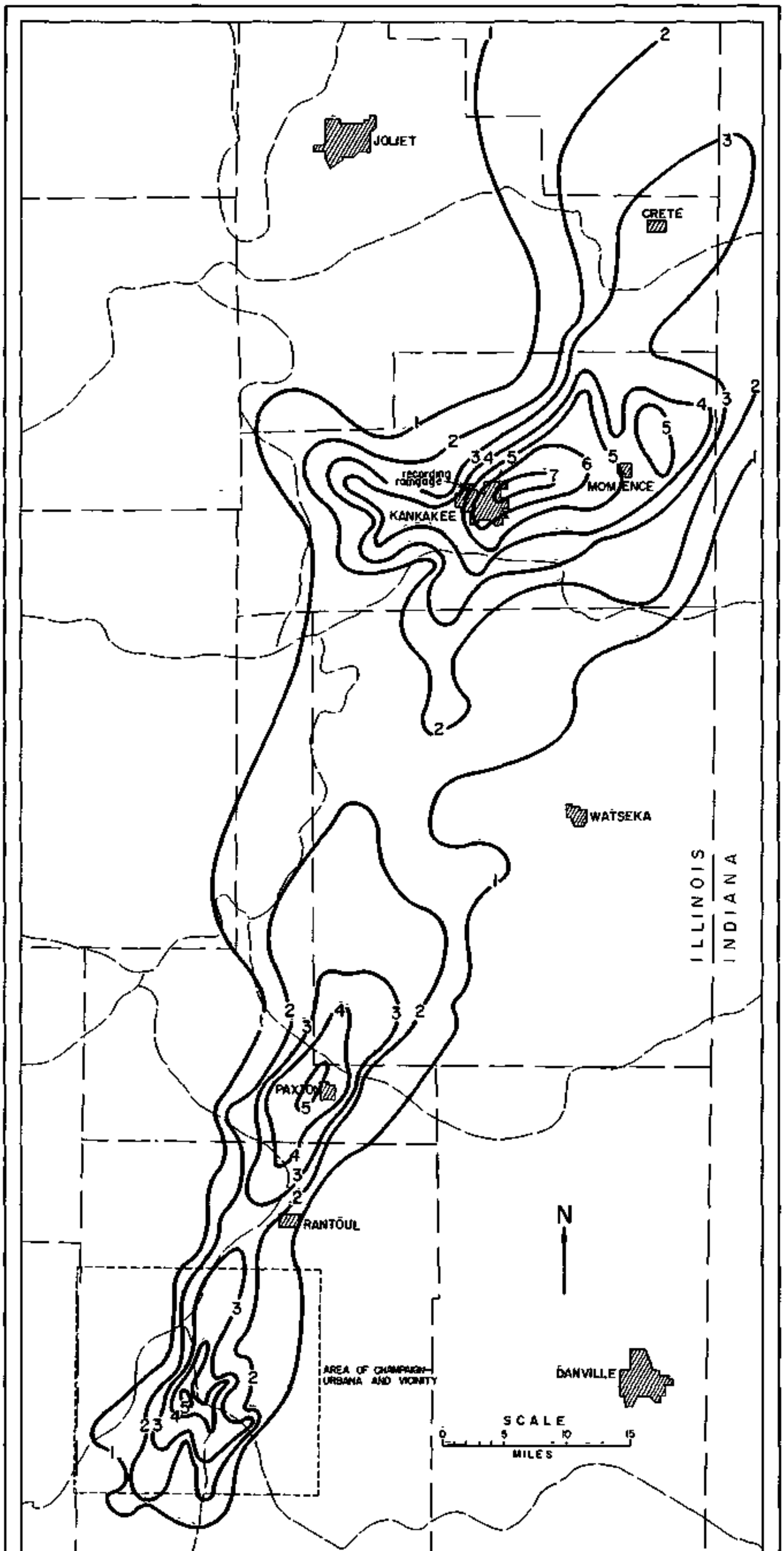


Figure 20. Total storm rainfall for May 20-21, 1959

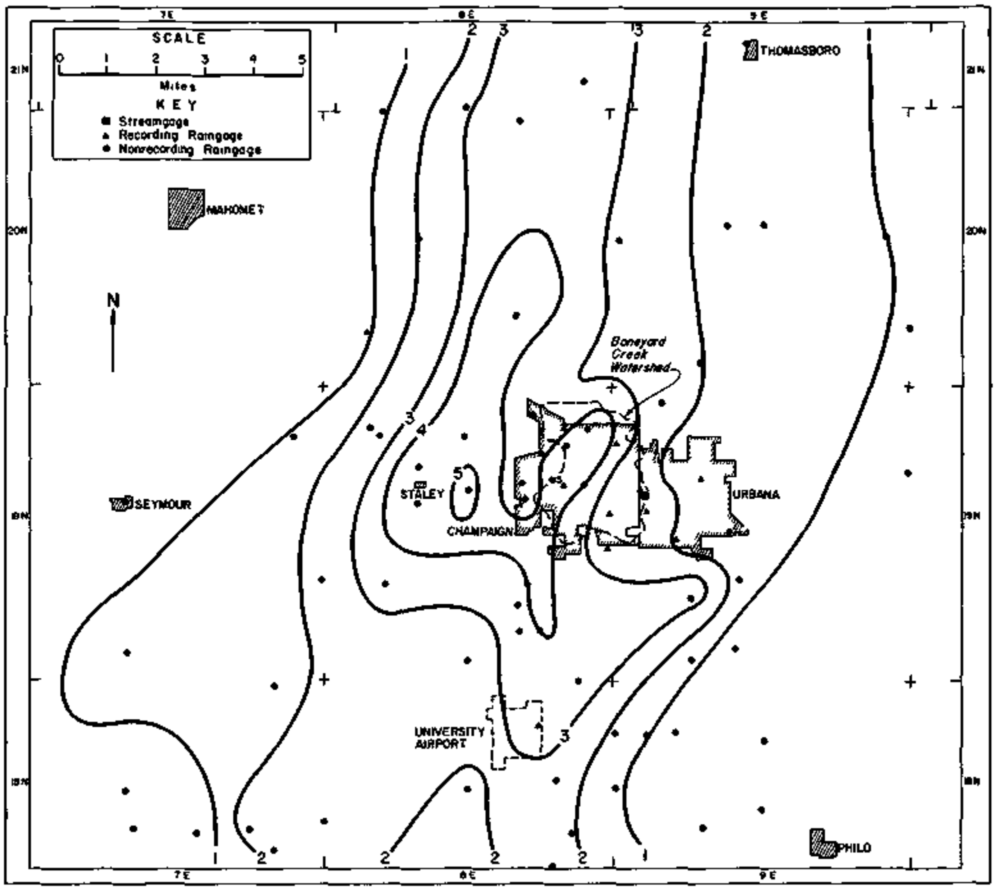


Figure 21. Total storm rainfall for Champaign-Urbana and vicinity, May 20-21, 1959

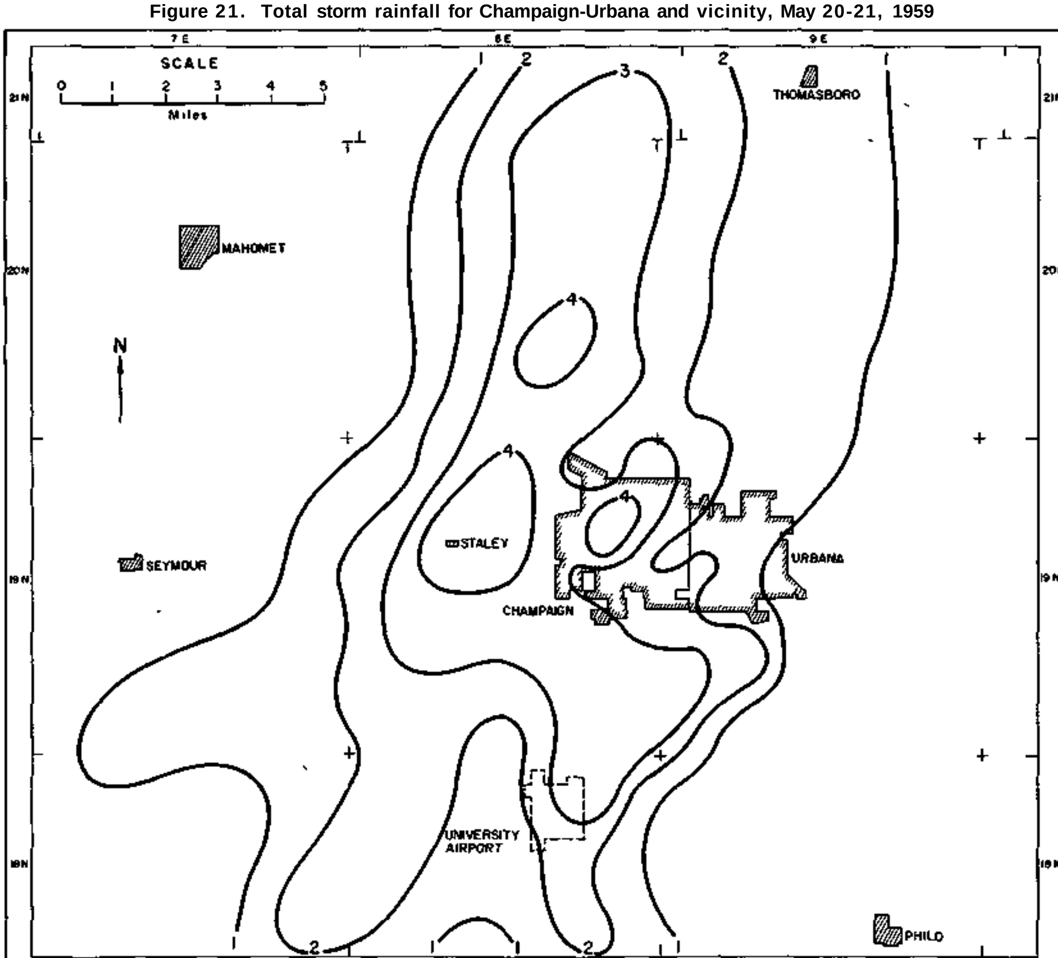
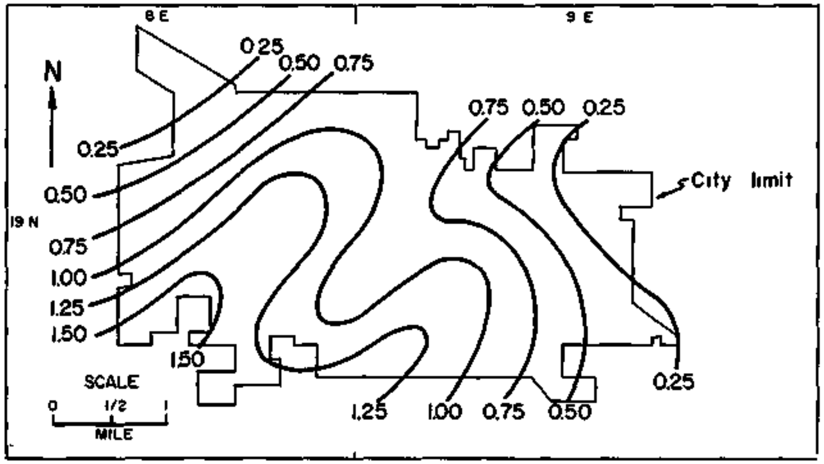
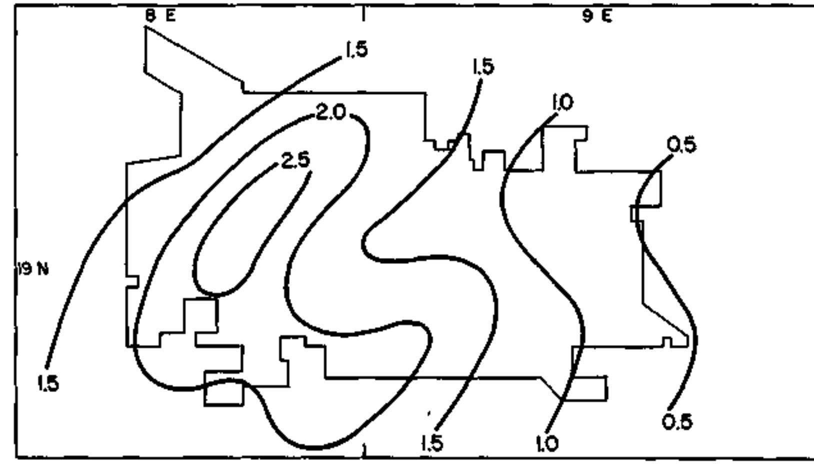


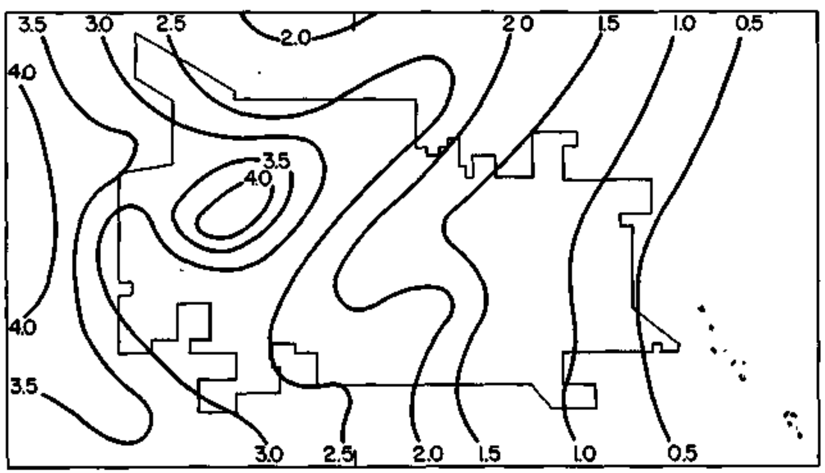
Figure 22. Maximum 3-hour rainfall amounts in storm of May 20, 1959



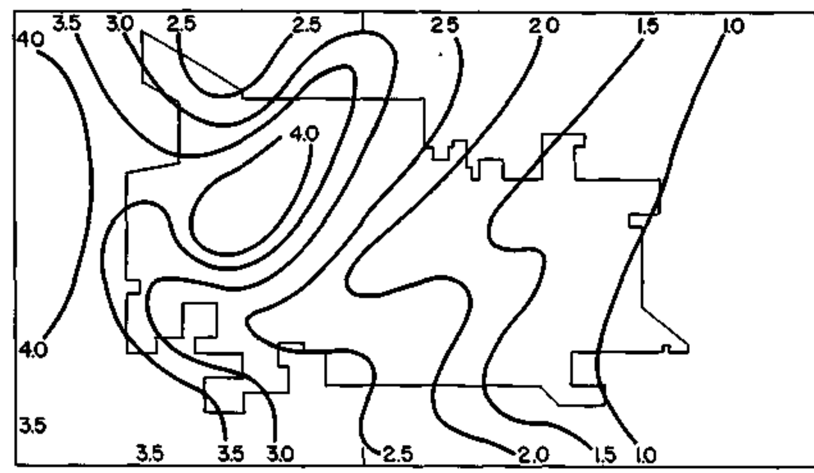
a. MAXIMUM 30-MINUTE RAINFALL



b. MAXIMUM 1-HOUR RAINFALL



c. MAXIMUM 2-HOUR RAINFALL



d. MAXIMUM 3-HOUR RAINFALL

Figure 23. Urban rainfall distribution on May 20, 1959

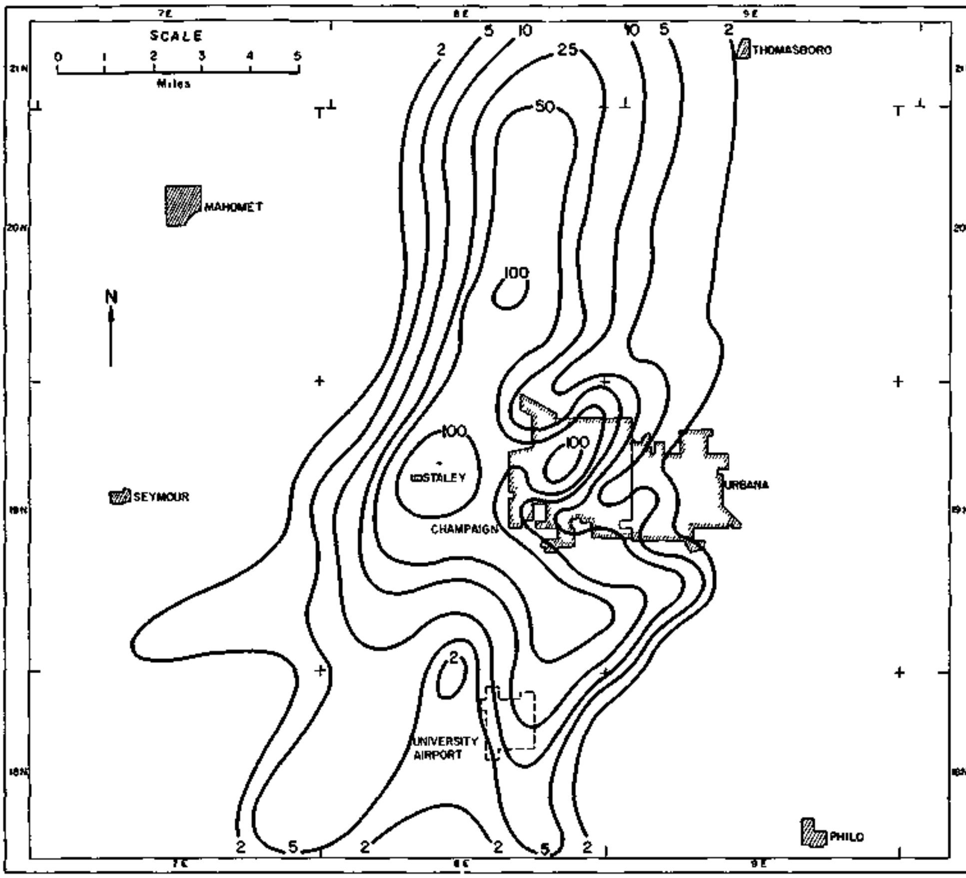
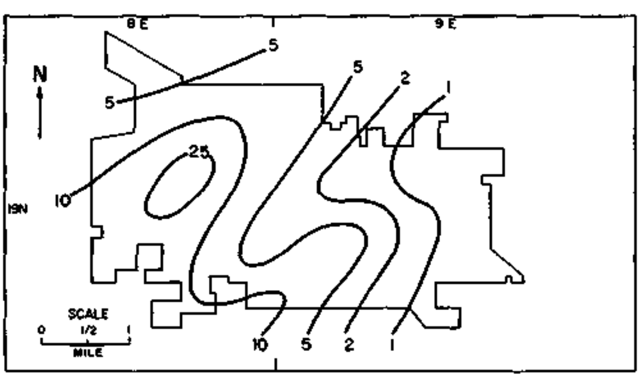
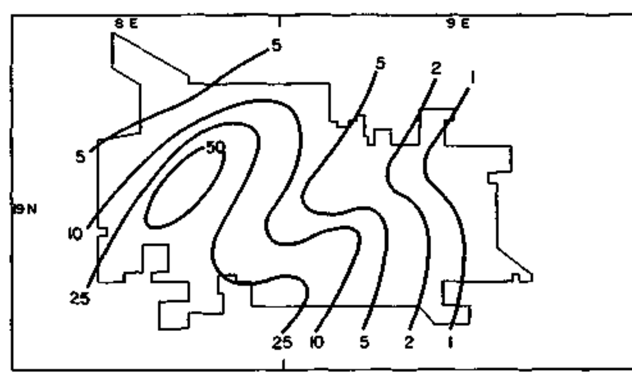


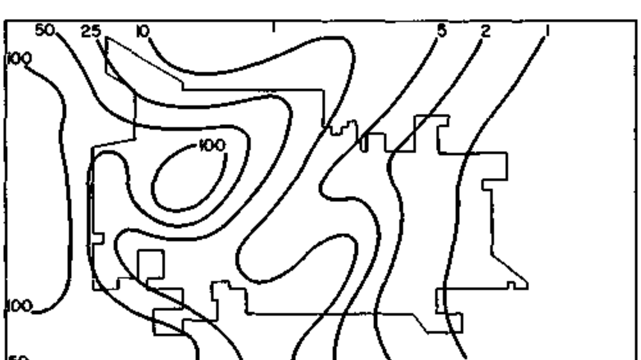
Figure 24. Average recurrence interval (years) of maximum 3-hour rainfall amounts in storm of May 20, 1959



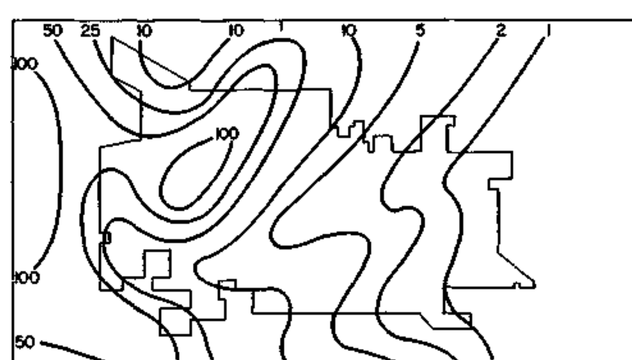
a AVERAGE RECURRENCE INTERVAL OF MAXIMUM
30-MINUTE RAINFALL



b. AVERAGE RECURRENCE INTERVAL OF MAXIMUM
1-HOUR RAINFALL



c. AVERAGE RECURRENCE INTERVAL OF MAXIMUM
2-HOUR RAINFALL



d. AVERAGE RECURRENCE INTERVAL OF MAXIMUM
3-HOUR RAINFALL

Figure 25. Variability in urban storm intensity on May 20, **1959**

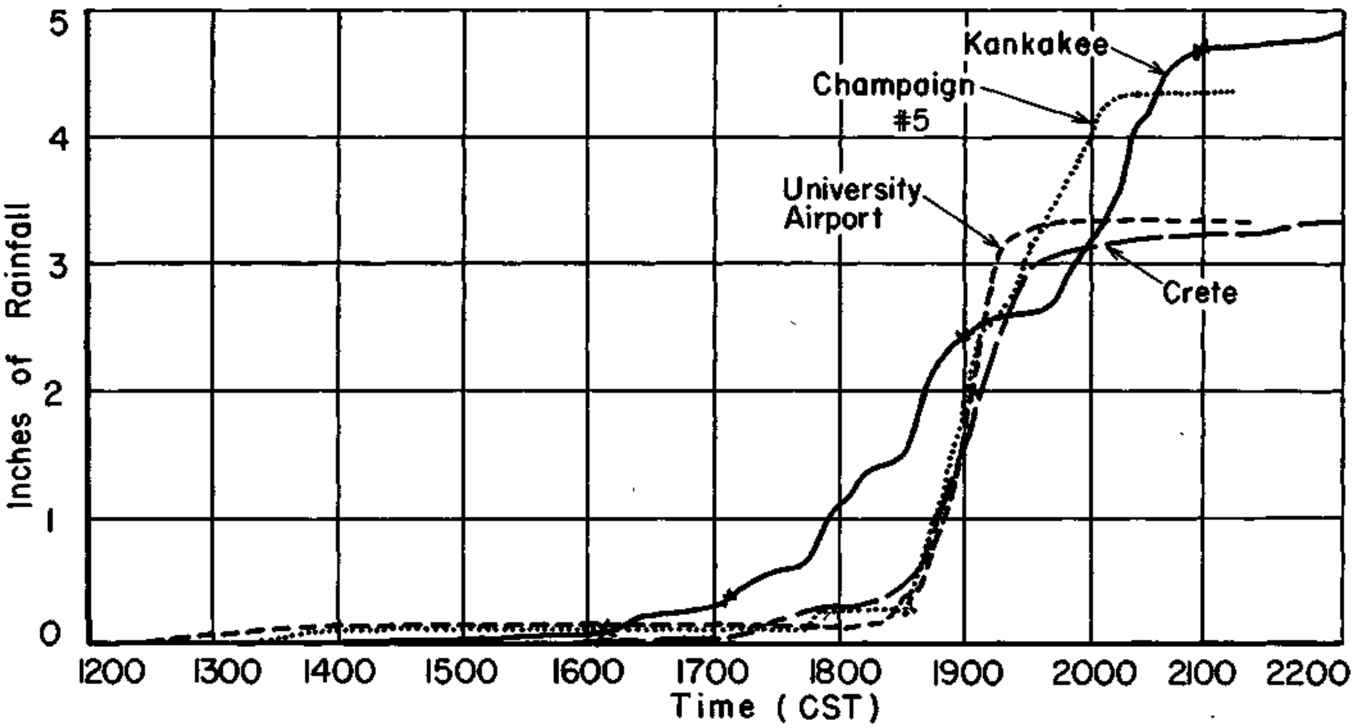


Figure 26. Mass curves of rainfall from selected stations far May 20, 1959

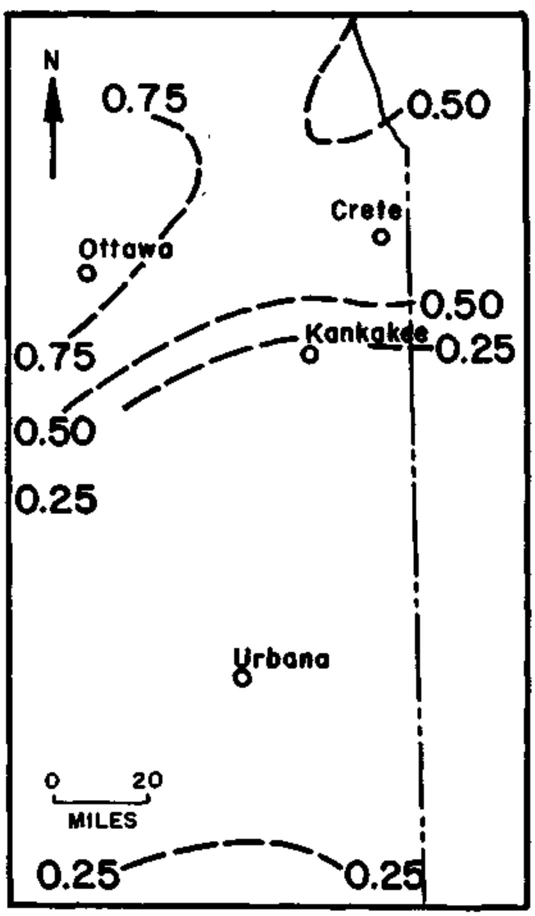


Figure 27. Total rainfall for May 15-19, 1959

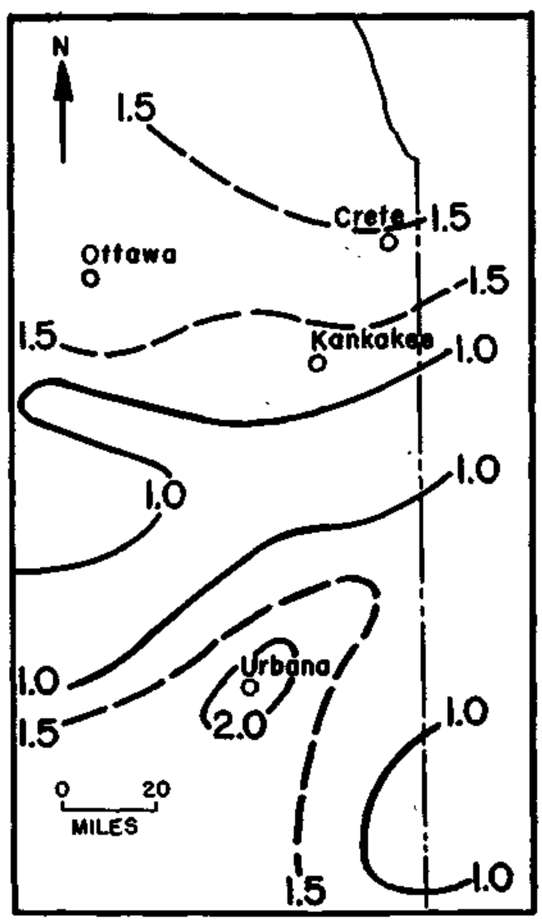


Figure 28. Total rainfall for May 10-19, 1959

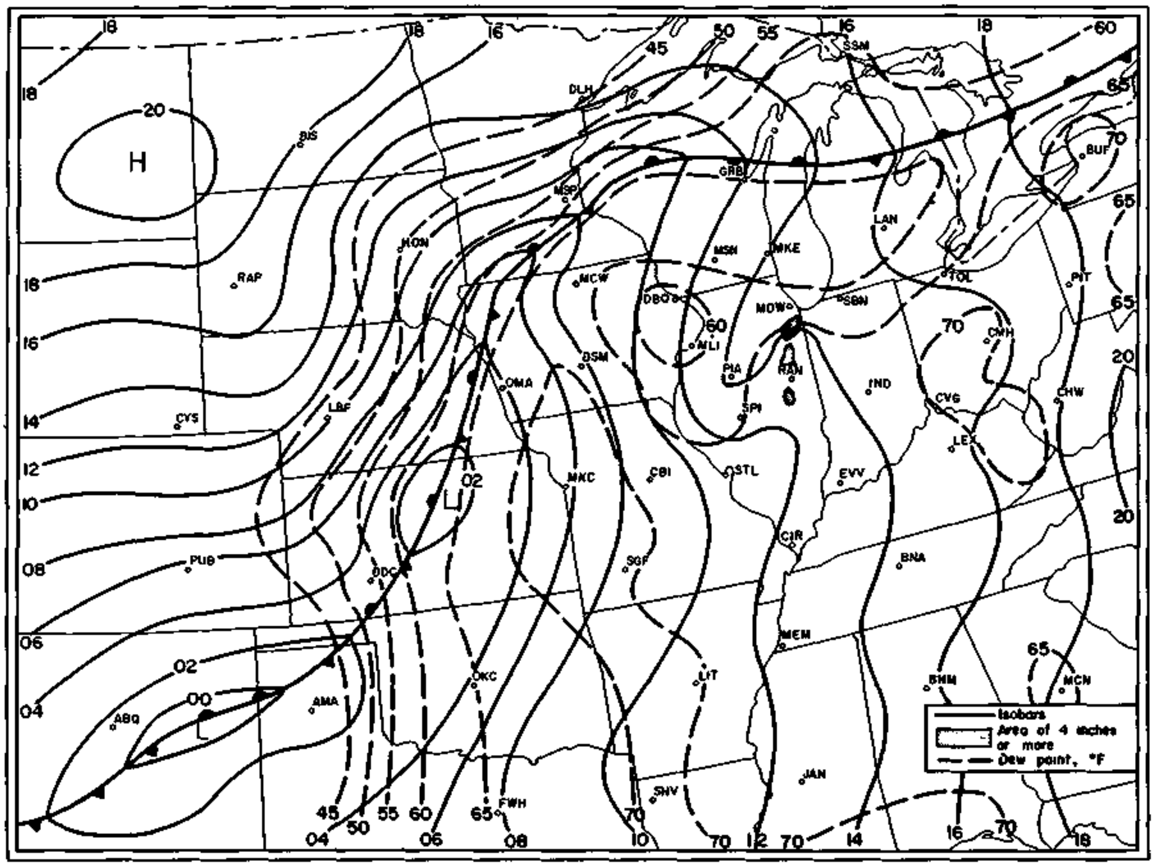


Figure 29. Surface synoptic map at 1800 CST on May 20, 1959

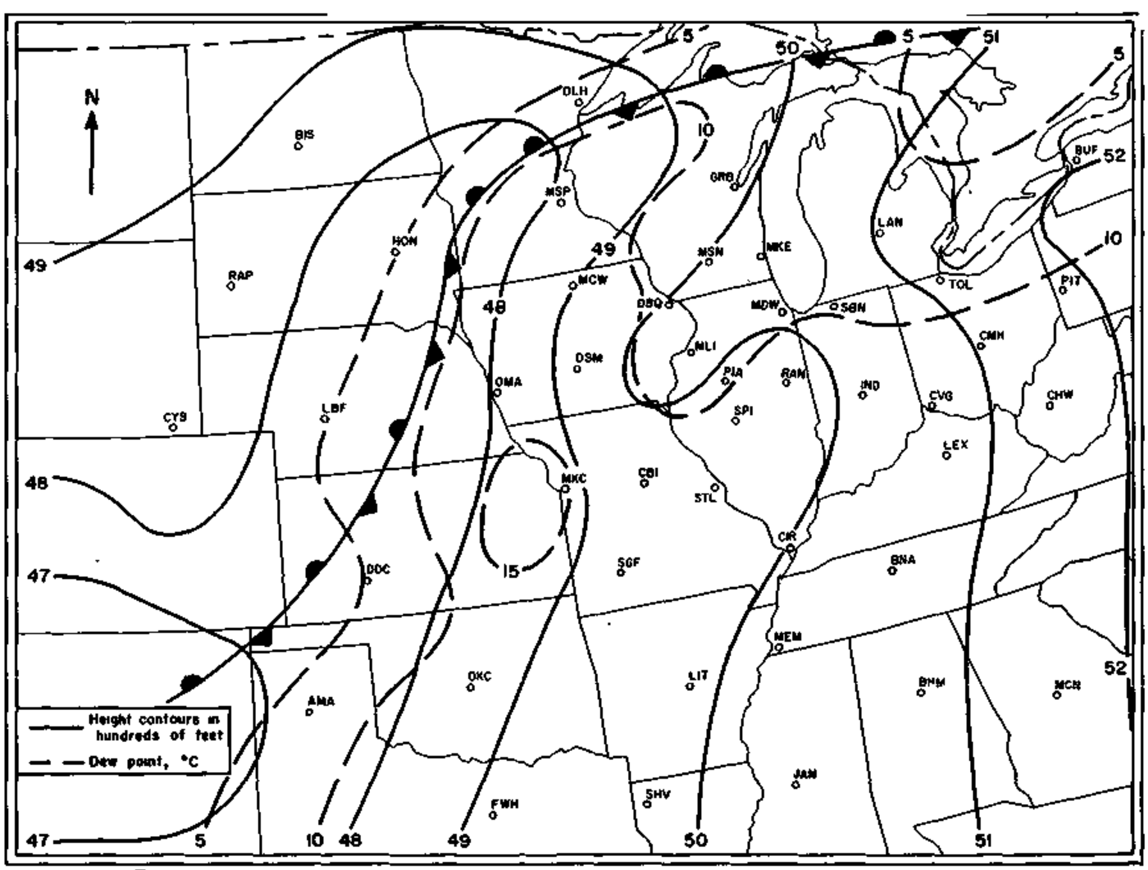


Figure 30. 850-mb map at 1800 CST on May 20, 1959

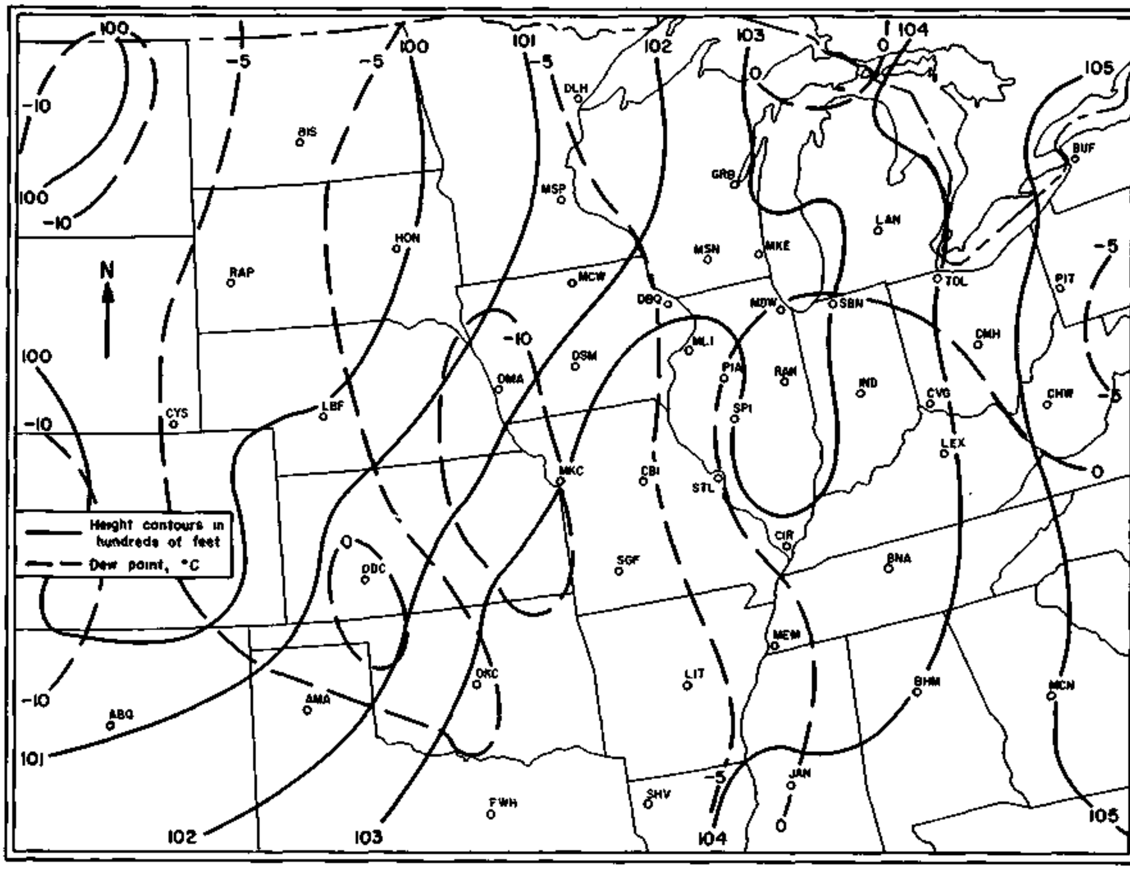


Figure 31. 700-mb map at 1800 CST an May 20, 1959

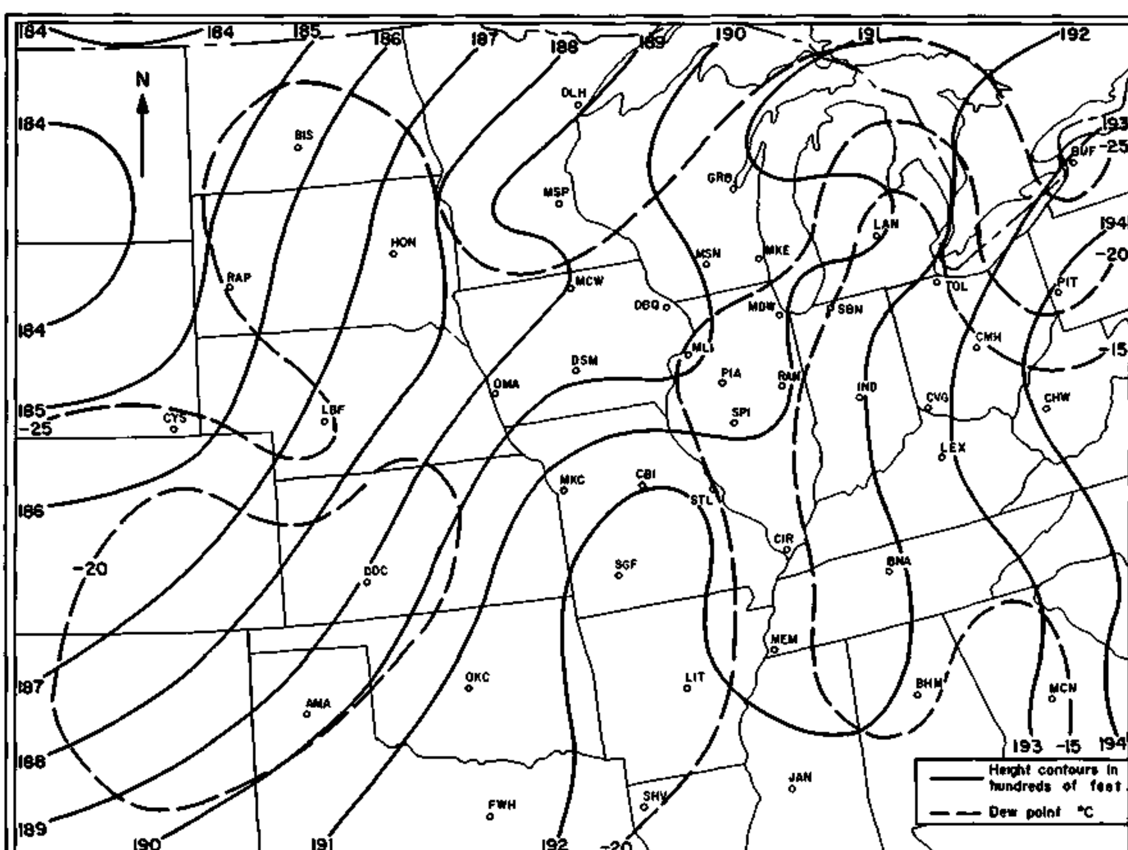


Figure 32. 500-mb map at 1800 CST on May 20, 1959

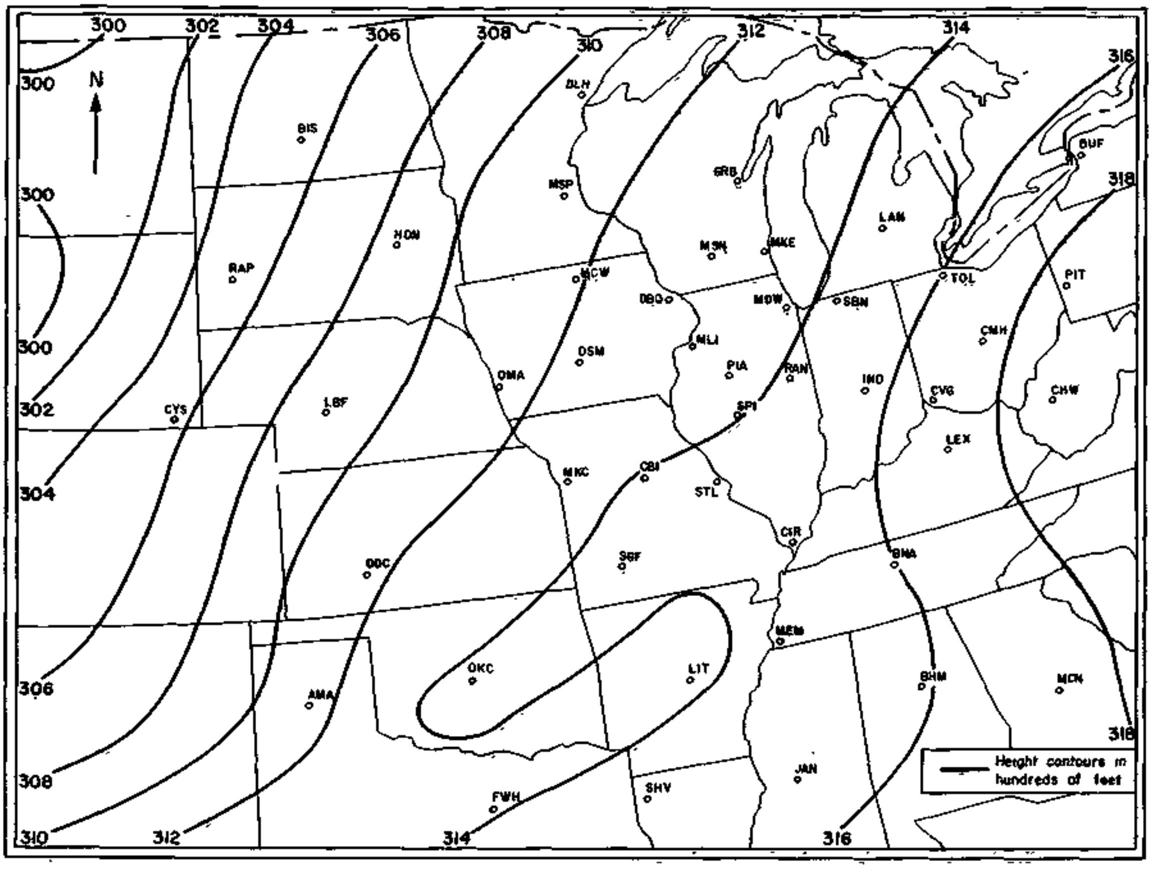


Figure 33. 300-mb map at 1800 CST an May 20, 1959

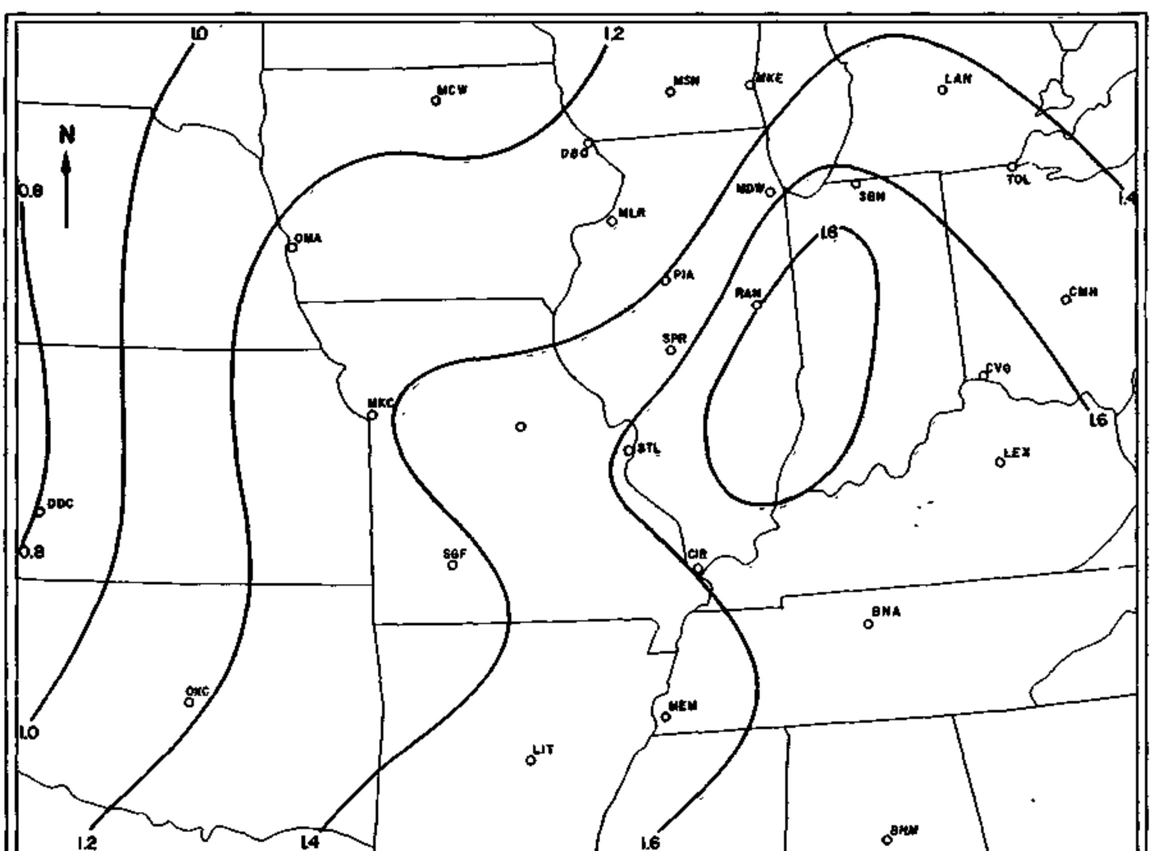


Figure 34. Precipitable water for surface to 400 mb at 1800 CST on May 20, 1959

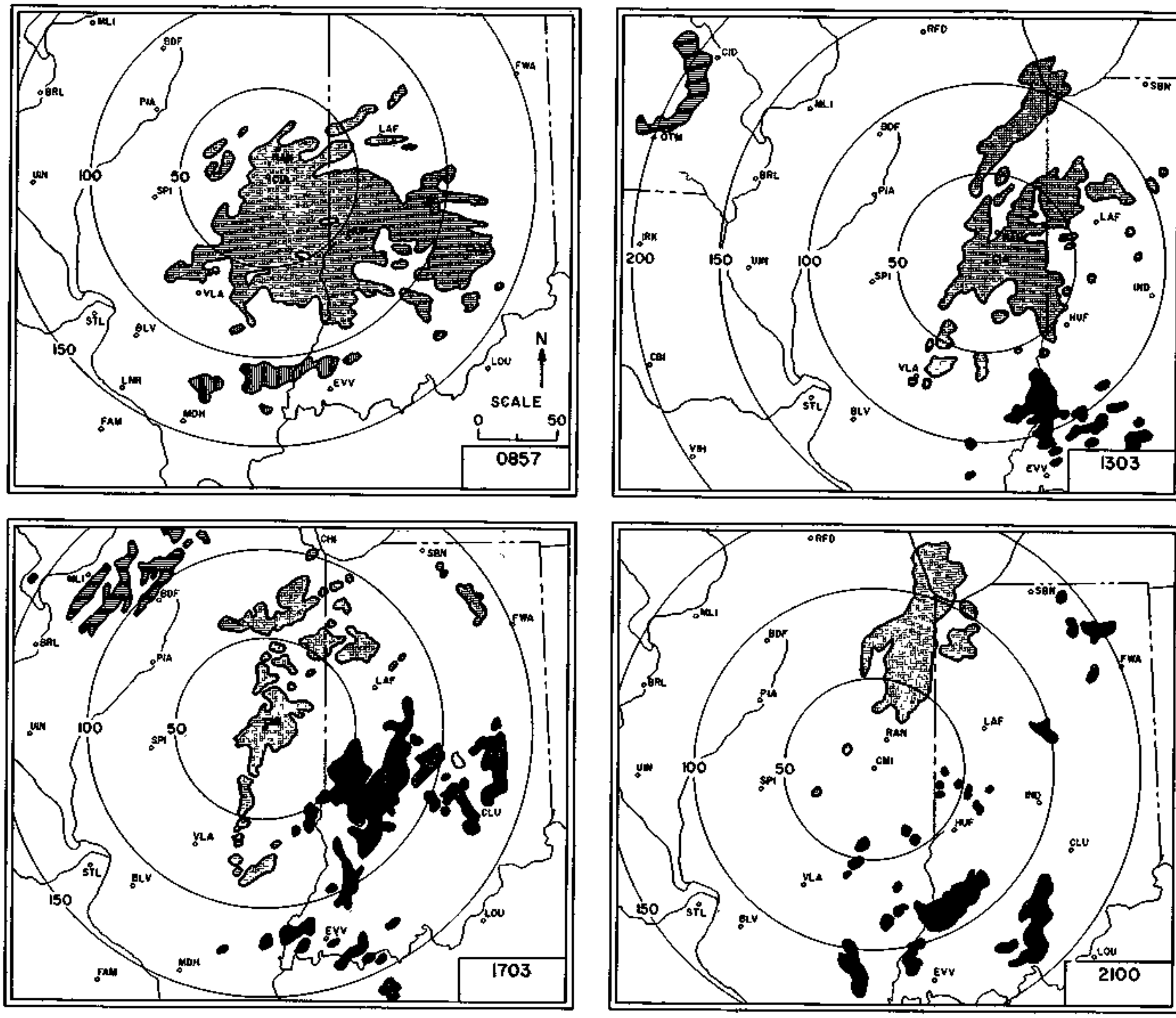


Figure 35. Radar echoes on May 20, 1959

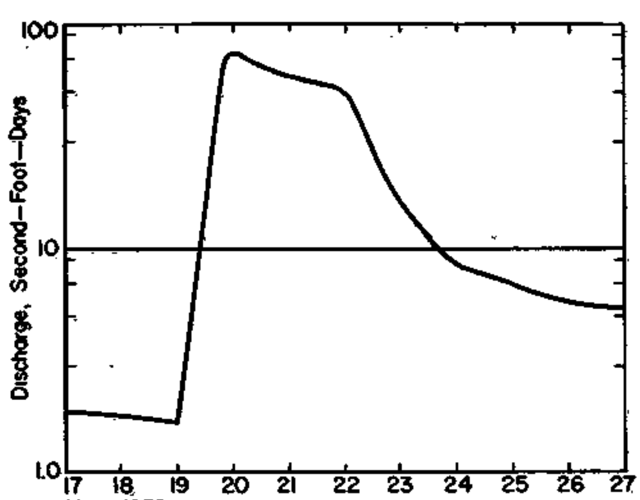


Figure 36. Hydrograph for Boneyard Creek at Urban a

STORM OF AUGUST 4-6, 1959

During the 65-hour period from 0100 CST on August 4 to 1800 CST on August 6, 1959, unusually heavy rainfall was recorded over an extensive area in northern Missouri, southern Iowa, western to southeastern Illinois, southwestern Indiana, and western Kentucky (Fig. 37). Four distinct storm periods occurred during this 65-hour period. Stations within the core of the storm experienced measurable rainfall in 15 to 30 hours of the 65-hour period, but most of it fell within a few hours. For example, at Morrisonville, Illinois, 90 percent of the total rainfall fell in 6 of the 16 hours with measurable rain, while at Downing, Missouri, 68 percent of the total occurred in 4 of the 30 rainy hours. During the 65-hour period, 48,000 square miles had rainfall in excess of 4 inches, 12,000 square miles had over 6 inches, and 1500 square miles experienced amounts exceeding 8 inches.

Isohyetal Patterns

A total storm isohyetal map is shown in Figure 37. This map is based upon data from the climatological network of the U. S. Weather Bureau, and gages operated by other organizations, such as the State Water Survey, State Division of Waterways, and the U. S. Geological Survey. No field survey was made of this storm. The 24-hour amounts in Illinois were below field survey requirements and the great areal extent of the storm made a field investigation extremely difficult to accomplish satisfactorily with available personnel.

Reference to Figure 37 shows that the heaviest amounts were recorded near the Missouri-Iowa border and in western and south central Illinois where amounts of 7 to 9 inches were widespread. Figure 38 shows an isohyetal map for a 14-hour storm period from 0100 to 1500 CST on August 4. Figure 39 shows the isohyetal pattern for the 48-hour period from 1800 on August 4 to 1800 on August 6. Division of the total storm into smaller increments was not possible with the available recording gage data. Figures 38 and 39 indicate little movement of the zone of maximum rainfall during the 3-day period.

Characteristics of Rainfall Distribution

Mass rainfall curves for several stations near the axis of the storm are shown in Figure 40. These curves are based upon hourly rainfall amounts published by the U. S. Weather Bureau.[7] The location of the stations is shown in Figure 38. The curves indicate that several storms occurred during the 65-hour rainfall period.

The first storm was initiated during the early morning of August 4. Hourly rainfall data indicate that a storm system developed in northern Missouri and southern Iowa about 0100 CST and propagated eastward to western Illinois by 0400 and to eastern Illinois by 0900. Another system appeared to develop over central Illinois and Indiana about 0100 CST and drift southward to extreme southern Illinois and western Kentucky by late forenoon.

A second major storm developed over northern Missouri and southern Iowa during the evening of August 4 and propagated eastward and southeastward, reaching western Illinois by 0400 CST on the 5th and southeastern Illinois by noon. Figure 40 shows that over 6 inches of rain was recorded at Ridgeway, Missouri, in the 10-hour period from 2100 CST on August 4 to 0700 on August 5. The Kentucky storm of August 5, depicted by the mass rainfall curve for Fords Ferry (Fig. 40), appeared to develop separately from the Missouri-Iowa-Illinois portions of the storm.

Figure 40 indicates that some portions of the extensive storm zone experienced another shower period during the afternoon of August 5. Another major storm developed over northern Missouri and southern Iowa for the third time in 18 hours during the evening of August 5 and spread out in all directions from this area, but with the greatest propagation and intensity to the east and southeast (Fig. 41). This storm system reached western Illinois by midnight and southern and southeastern Illinois by early forenoon. Again, a separate storm system appeared to develop over western Kentucky during the early forenoon of August 6. This portion of the storm produced over 5 inches of rain between midnight and 0800 CST, August 6, at Morrisonville in south central Illinois (Fig. 40).

Depth-Duration-Area Relations

Area-depth relations for the total storm (Fig. 37), for the first storm period (Fig. 38), and for a combination of the remaining storm periods (Fig. 39) are shown in Table 9 for the entire storm area from Missouri and Iowa to Illinois and western Kentucky. Table 10 shows similar relations for the Illinois portion of the storm. Table 11 illustrates the relative intensity of this storm in Illinois by showing the area encompassed by rainfall amounts which equal or exceed those expected for selected recurrence intervals for storm periods of 48 and 72 hours, based upon studies by Huff and Neill.[8] Thus, an area of 7600 square miles received rainfall amounts equalling or exceeding the 48-hour rainfall expected at any given point in this region on an average of once in 2 years, while 11,000 square miles had amounts exceeding the 2-year frequency of 72-hour rainfall. The 2-day and 3-day totals were the most outstanding feature of this storm, rather than short-period or single storm intensities.

Antecedent Rainfall

Figures 42 and 43 show the total rainfall in Illinois for periods of 5 and 10 days preceding 'the August 4-6 storm. At this time of the year, the normal 5-day and 10-day rainfall is approximately 0.55 inch and 1.10 inches, respectively, within the storm

TABLE 9

DEPTH-DURATION-AREA DATA, ENTIRE STORM ZONE, AUGUST 4-6, 1959

Duration (hours)	Depth (in.) for given area (sq. mi.) 100	200	500	1000	2000	5000	10,000	20,000	50,000	100,000
15	5.2	4.8	4.3	3.9	3.5	2.9	2.5	2.0	---	---
48	9.5	8.9	8.1	7.4	6.8	6.0	5.4	4.6	3.3	2.0
65	9.5	9.2	8.7	8.3	7.7	6.9	6.2	5.3	3.9	2.4

TABLE 10

DEPTH-DURATION-AREA DATA, ILLINOIS, AUGUST 4-6, 1959

Duration (hours)	Depth (in.) for given area (sq. mi.) 100	200	500	1000	2000	5000	10,000	20,000
10	3.2	3.1	2.9	2.7	2.4	1.9	1.5	---
38	7.3	7.1	6.7	6.3	5.7	4.8	3.9	2.9
62	8.5	8.3	7.8	7.4	6.8	5.8	4.7	3.5

TABLE 11

RECURRENCE INTERVAL OF MAXIMUM RAINFALL AMOUNTS, ILLINOIS, AUGUST 4-6, 1959

Duration (hours)	Area (sq. mi.) with rainfall equalling or exceeding given recurrence-interval values (yrs.) 2	5	10	25	50
48	7,600	4200	2200	500	100
72	11,000	5400	3000	800	200

zone in Illinois. Figure 42 shows below normal amounts in the storm zone for the 5 days preceding the storm over most of the storm zone. The 10-day map (Fig. 43) shows below normal to near normal amounts over most of the storm zone. Thus, antecedent rainfall does not appear to have been a,major factor in flooding associated with this 3-day storm period.

Synoptic Weather

Figure 44 shows the surface synoptic maps at selected times during the 3-day storm period. The map for 0600 CST, August 4, is representative of surface conditions at the time of the first major storm in the heavy rainfall zone (Figs. 38, 40). The rainfall occurred in hot, humid air to the south of a' warm front with waves which extended across northern Illinois. This warm front had moved northward from extreme southern Illinois during the previous 24 hours. Dew point temperatures exceeded 70°F throughout the storm zone, which extended through northern Missouri, southern Iowa, western and central Illinois to western Kentucky. The map for 0600 CST, August 5, is representative of conditions in the second major storm period over Illinois and adjacent areas. Exceptionally heavy rainfall occurred in northern Missouri with this storm (Fig. 40). The heavy rainfall zone was located north of and approximately parallel to a warm front extending ESE from northern Missouri through southern Illinois. Dew point temperatures again exceeded 70°F. The third and fourth maps illustrate conditions during the last major storm of the 3-day period in which Illinois received its heaviest amounts. The rainfall occurred again north of and approximately parallel with the warm front which remained quasi-stationary on August 5-6. Dew points remained in the low 70's, and possible wave action on the warm front is indicated on the map for 0000 CST, August 6. Mean air temperatures during the 3-day storm period were in the high 70's to low 80's in the storm region. With diurnal cooling, the differences between dew point and air temperatures decreased 2 to 5 degrees at night when the heavy storms developed over Illinois and Missouri. The dew point gradient in southern Wisconsin and Minnesota represents the northern edge of the rain area during August 4-6 and resulted primarily from strong daytime evaporation in the rain area. The quasi-stationary front was located primarily from analyses of the rainstorm characteristics and radar echo patterns.

Figure 45 shows upper air maps for 0600 CST, August 4, during the first major storm. Similar maps are shown in Figure 46 for 1800 CST, August 5, a few hours before development of the storm which produced the heaviest rainfall of the 3-day period in Illinois. Figure 46 shows minor troughs at 850 mb and 700 mb in the storm region oriented approximately parallel with the surface rainfall pattern. At 500 mb a minor trough with a NNW-SSE orientation is indicated over Illinois. Dew point ridges are present at 700 mb and 500 mb in the storm region. Divergence is indicated by a weak ridge over Illinois at the 300-mb level in Figure 46.

Figure 47 shows the precipitable water for the layer from the surface to 400 mb at 1800 CST, August 5, preceding the last major storm of the August 4-6 period whichproduced the heaviest rainfall in Illinois. Figure 47 indicates that the rainstorm zone was lying near and approximately parallel to a ridge in the precipitable water pattern. Analysis of other data indicated that the precipitable water ranged from 1.5 to 2.1 inches in the storm zone during the 3-day storm period. Normal for this period is approximately 1.3 inches. Calculation of Showalter stability indices showed values of -1 to -4 during the rainfall periods of August 4-6. The above data indicate the presence of an abnormally moist and unstable atmosphere in the storm zone during the 3-day period.

Summary

The August 4-6, 1959, storm resulted from four distinct storm periods within 65 hours. The 2-day and 3-day cumulative totals and the great areal extent were the most outstanding features of this storm which extended from northern Missouri through Illinois to western Kentucky. Nearly 20 percent of Illinois received storm rainfall amounts exceeding the average 2-year frequency for a 72-hour period, and nearly 10 percent of the state experienced a 5-year frequency for this duration.

Analysis of synoptic weather conditions indicated an abnormally moist and unstable atmosphere in the storm region. The heaviest rainfall in Illinois occurred during the presence of a quasi-stationary front south of the storm core which was oriented approximately parallel with the surface rainfall axis. Other features present at that time, typical of severe rainstorms in Illinois, were. minor troughs at 850 mb, 700 mb, and 500 mb; a dew point ridge at 700 mb and 500 mb; and a precipitable water ridge for the layer from the surface to 400 mb.

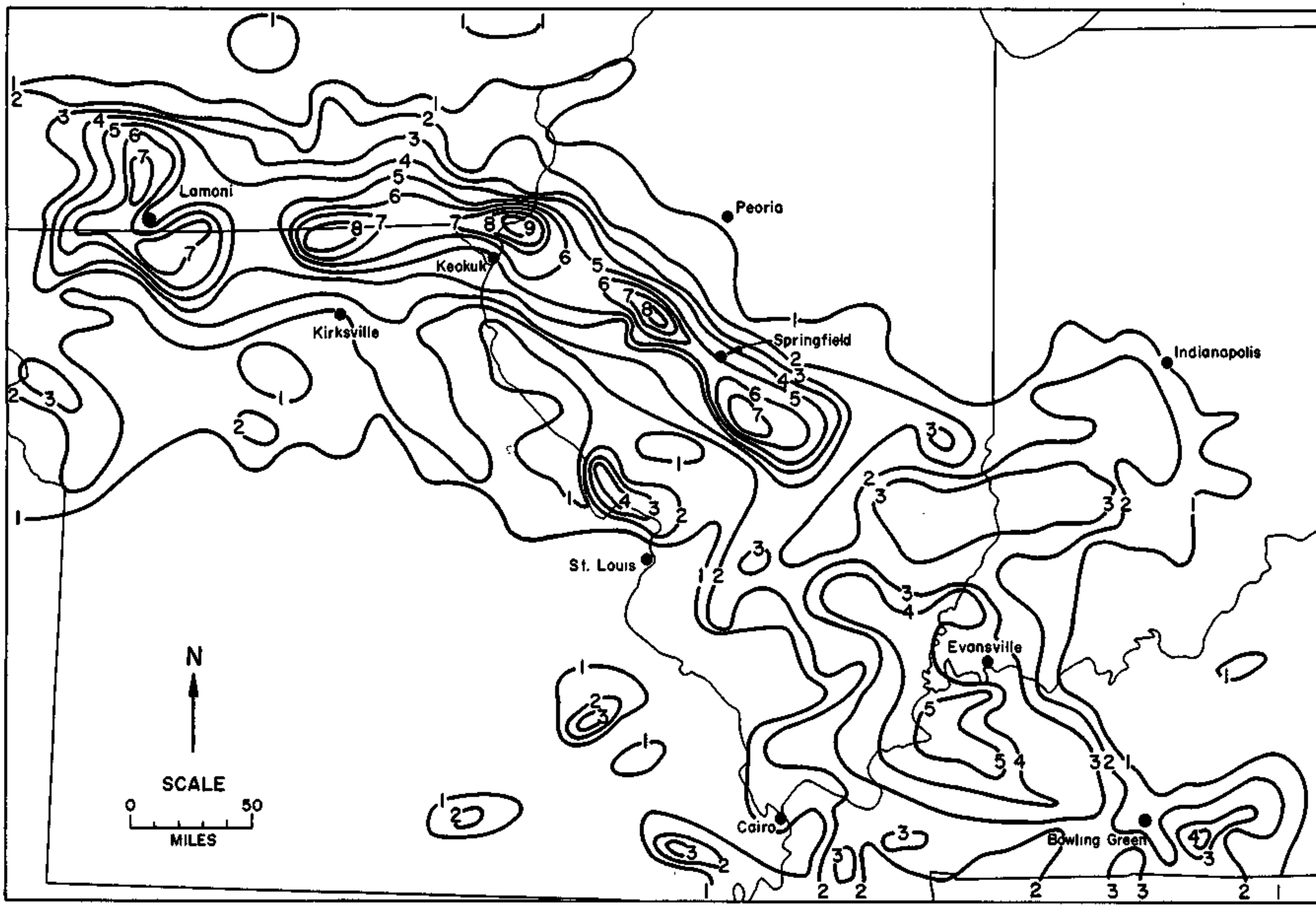


Figure 37. Total storm rainfall for August 4-6, 1959

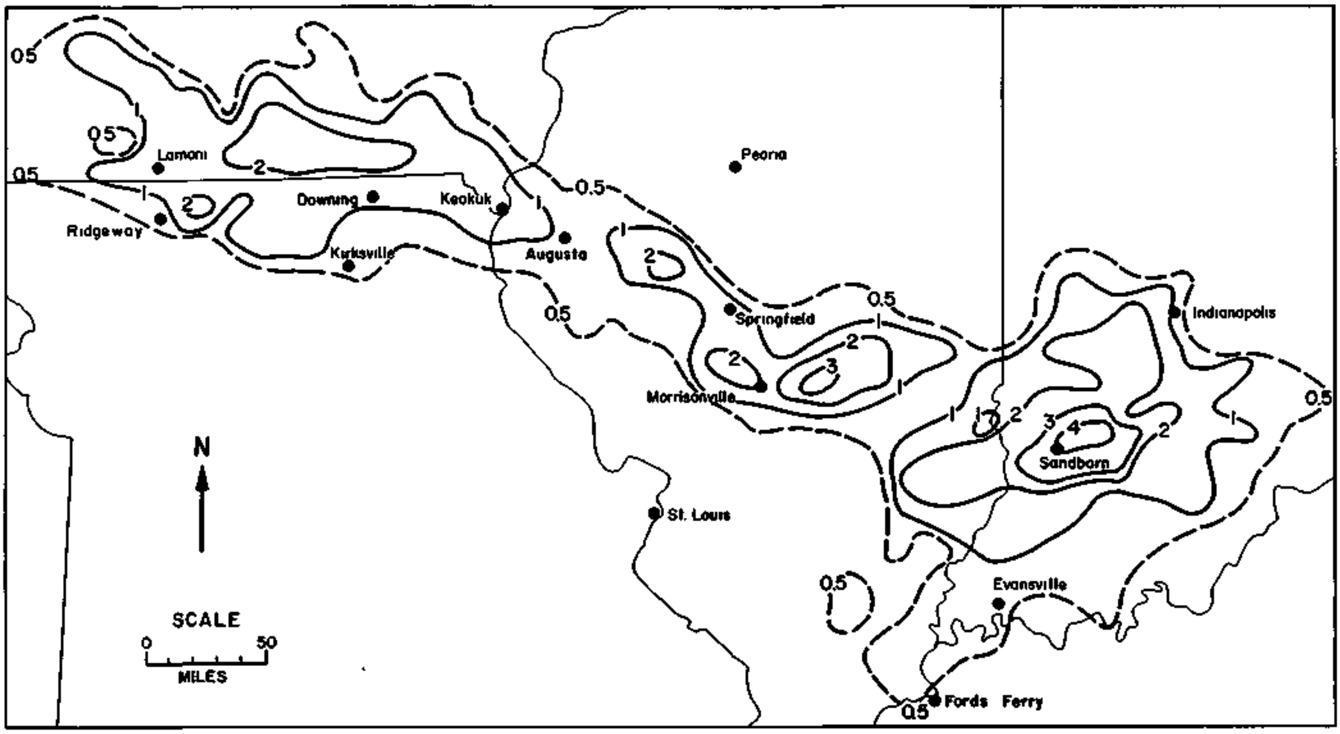


Figure 38. Total storm rainfall for 0100 to 1500 CST on August 4, 1959

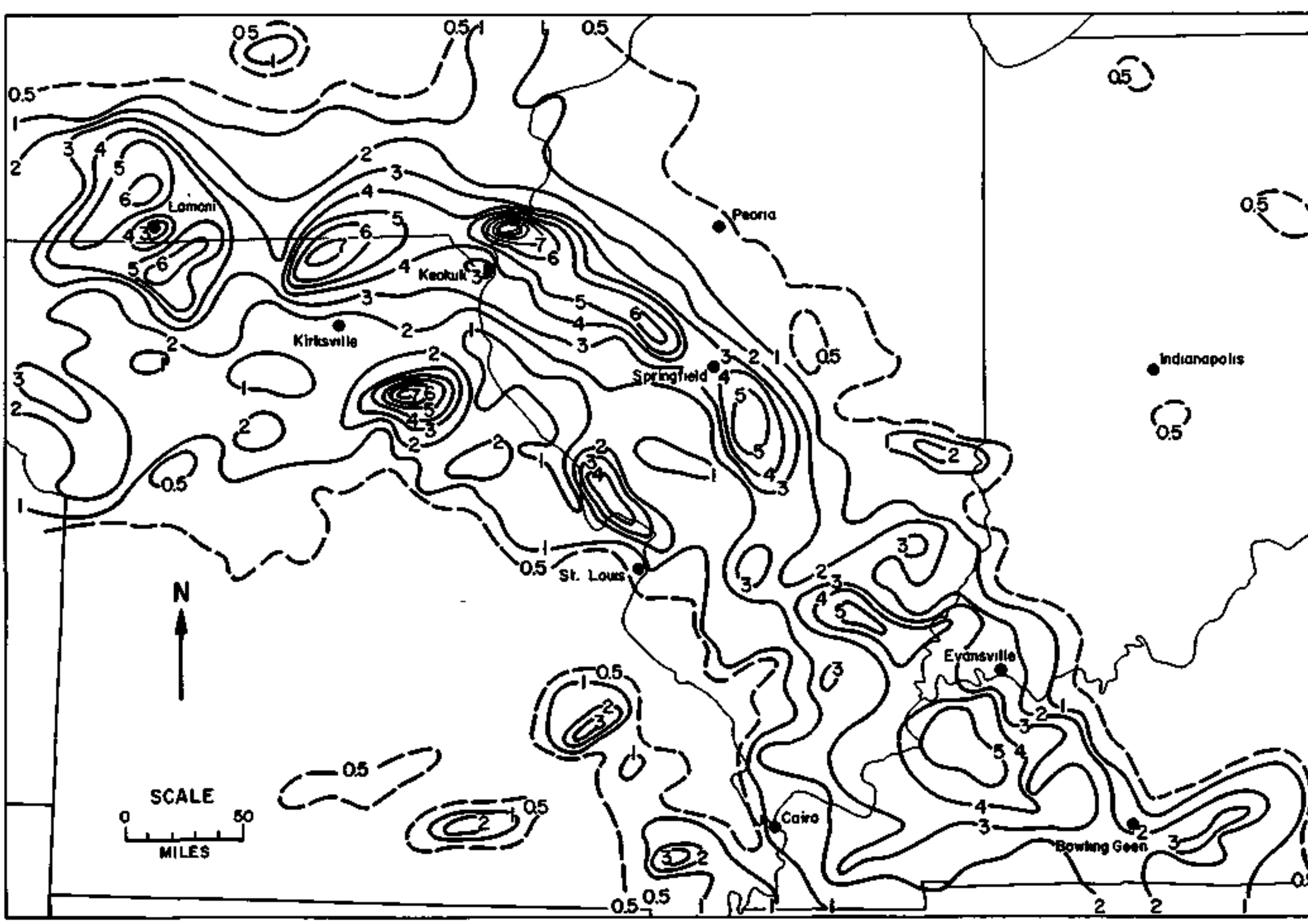


Figure 39. Total storm rainfall from 1800 CST on August 4 to 1800 CST on August *6,* 1959

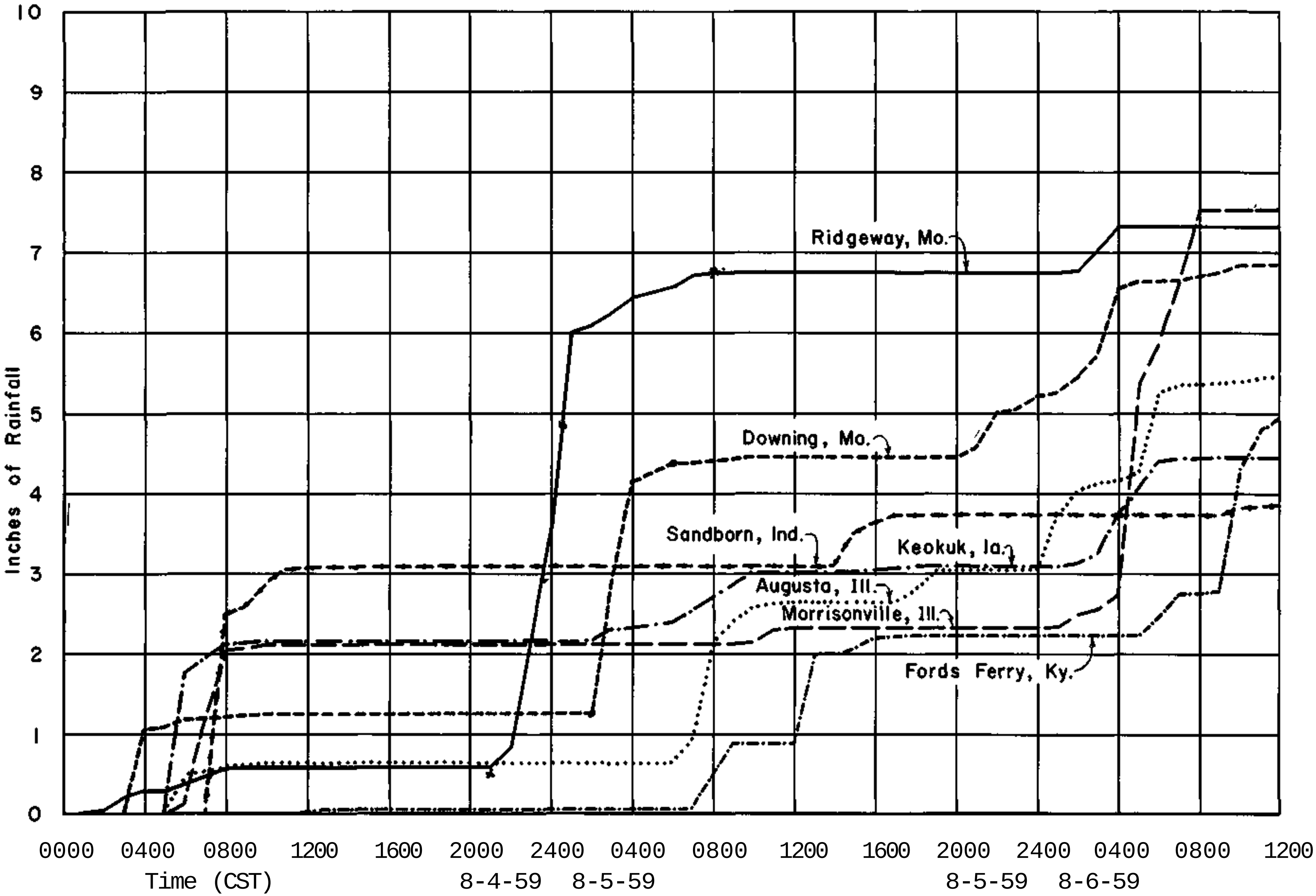


Figure 40. Mass curves of rainfall from selected stations for August 4-6, 1959

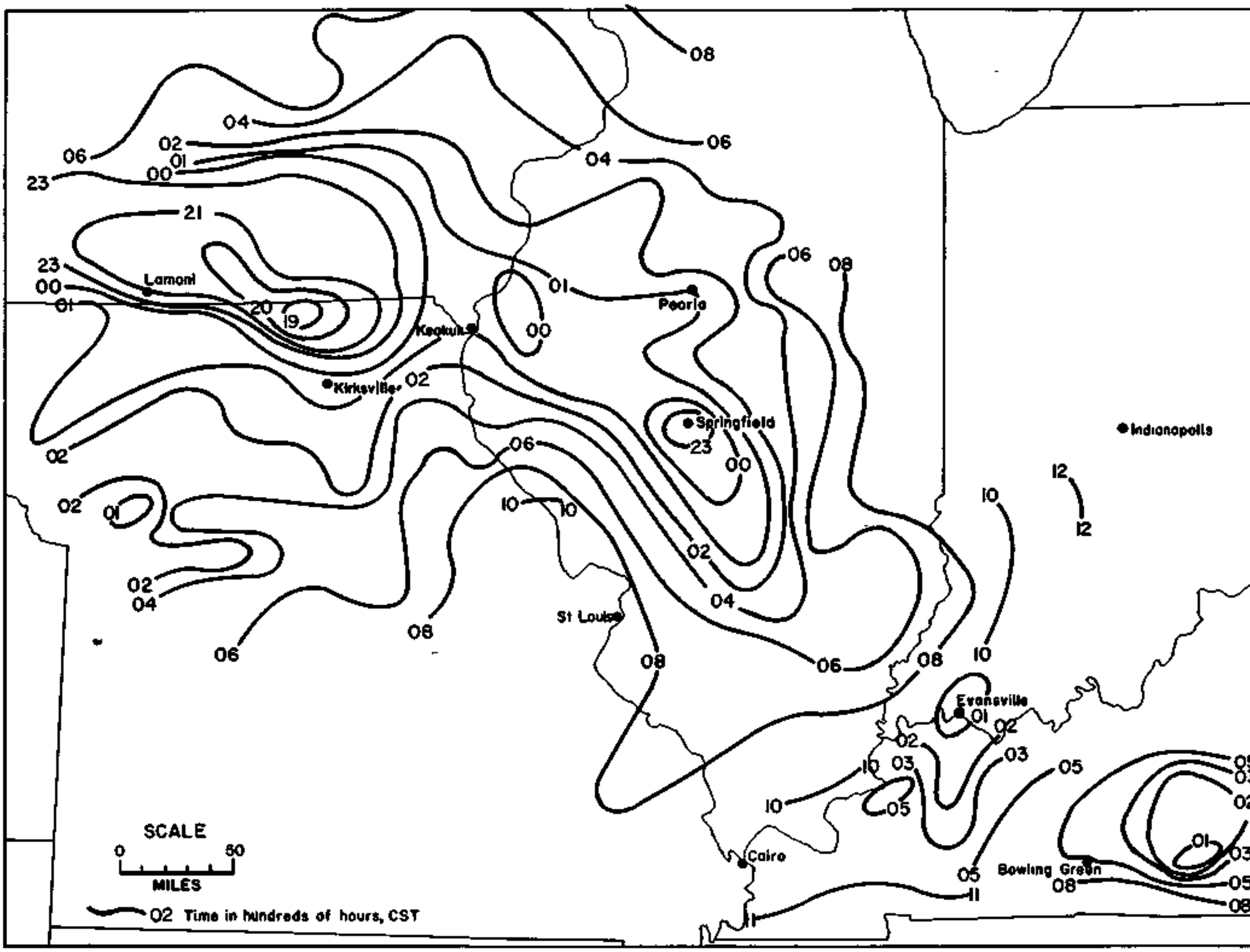


Figure 41. Isochrones of rainfall initiation, night of August 5-6, 1959

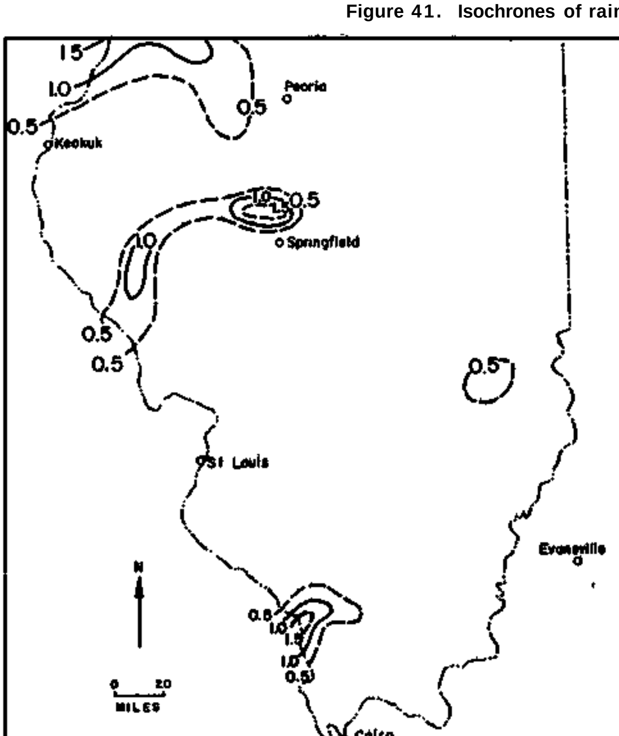


Figure 42. Total rainfall for July 30 - August 3, 1959

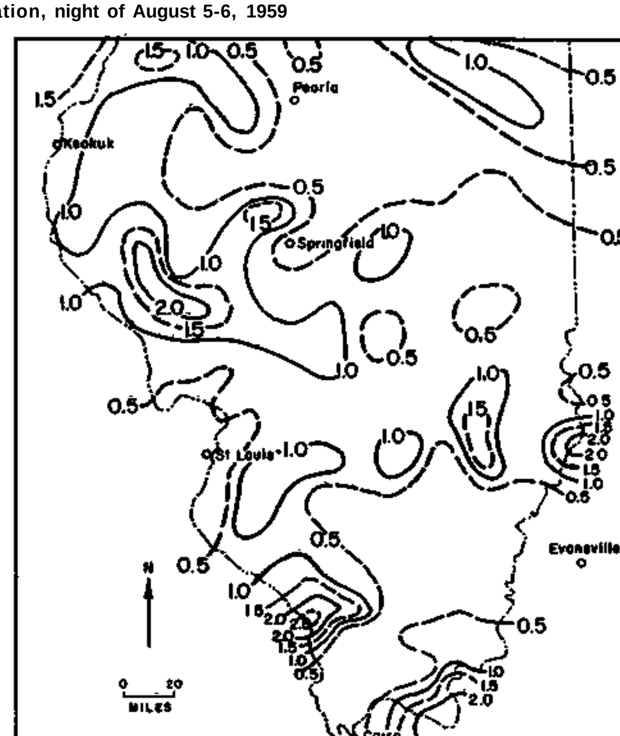
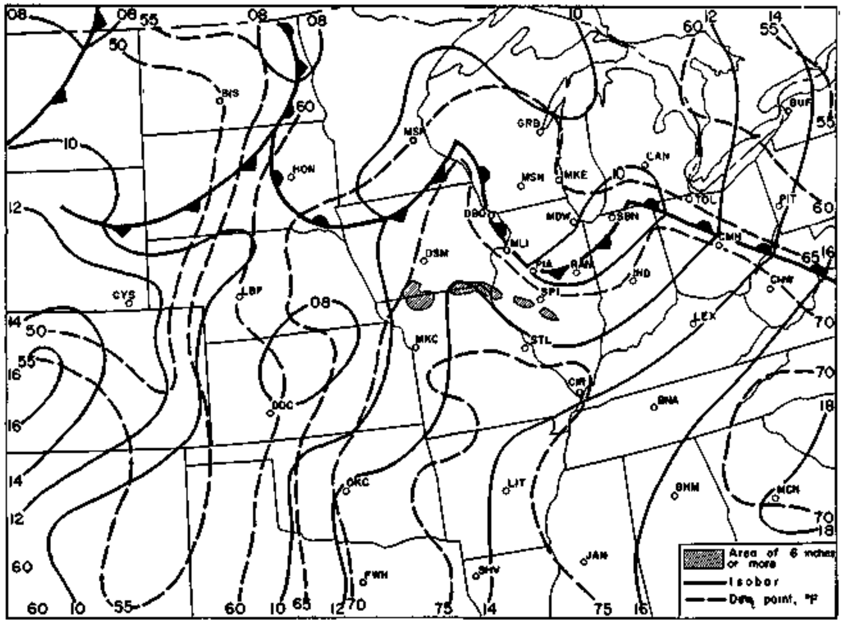
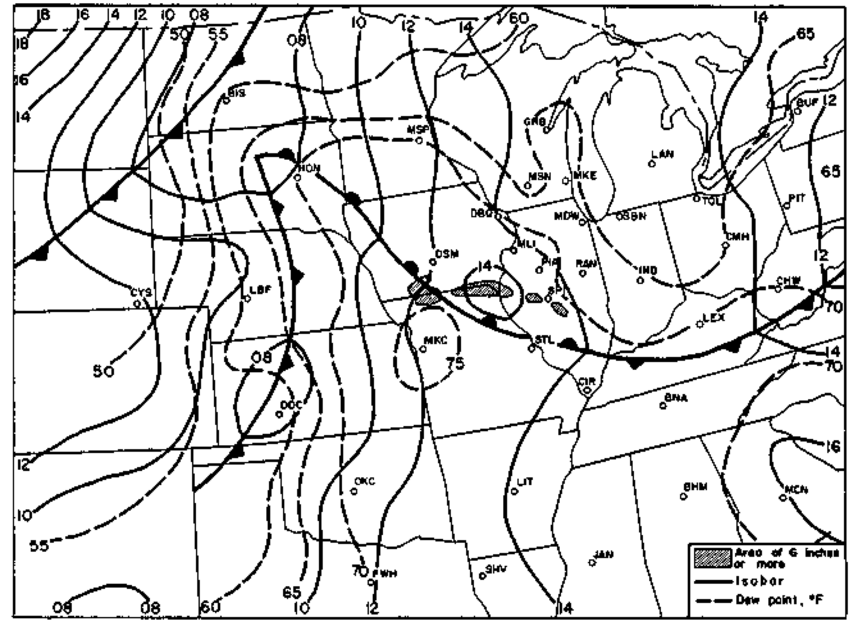


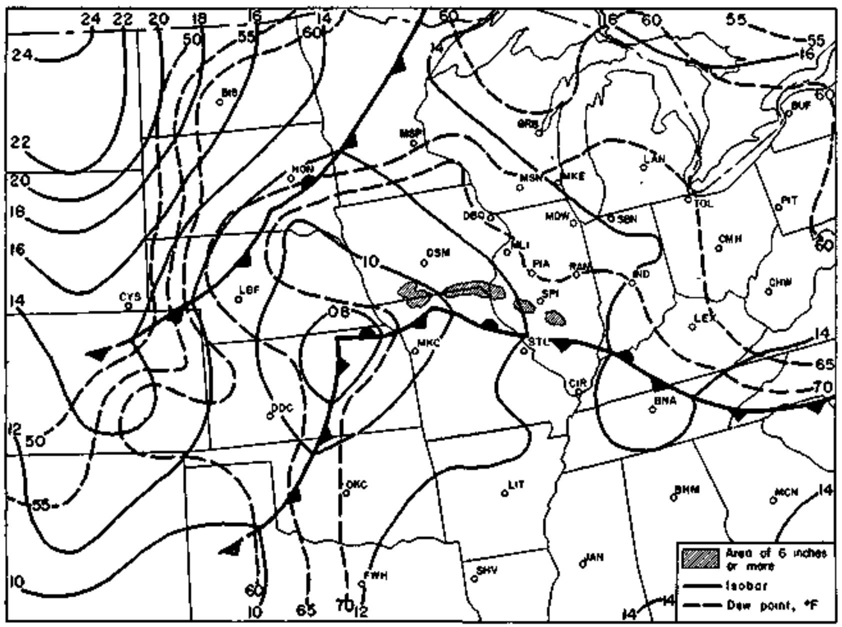
Figure 43. Total rainfall for July 25 - August 3, 1959



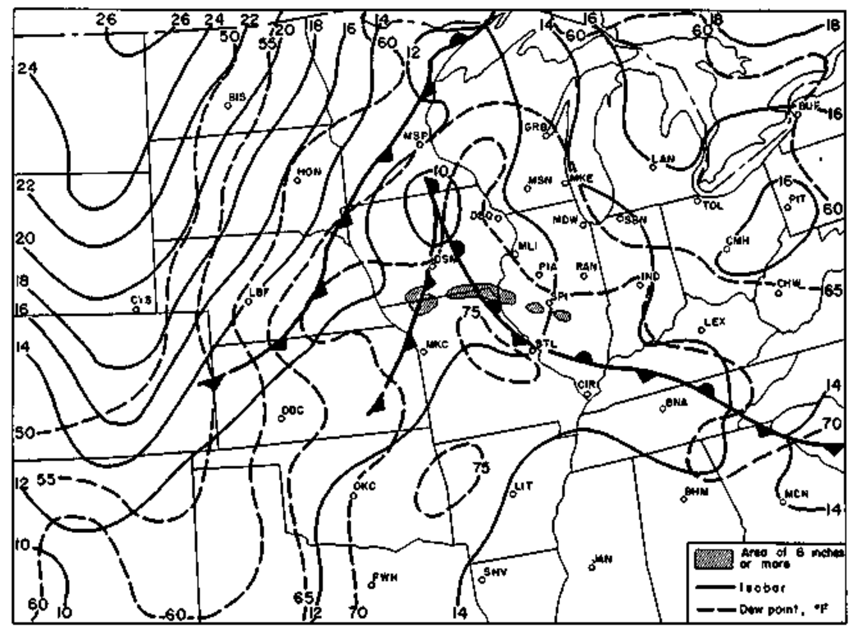
a 0600 CST AUGUST 4, 1959



b 0600 CST AUGUST 5, 1959

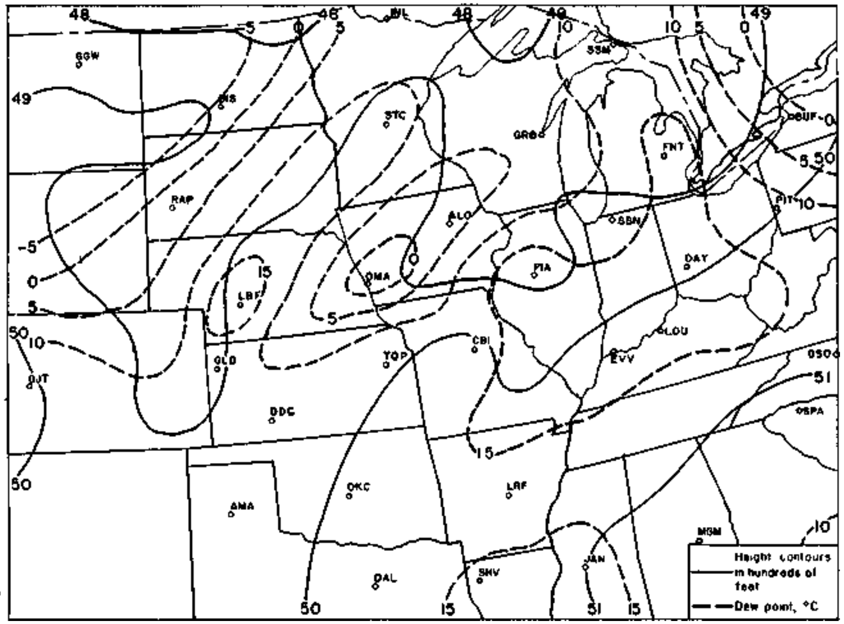


c 0000 CST AUGUST 6, 1959

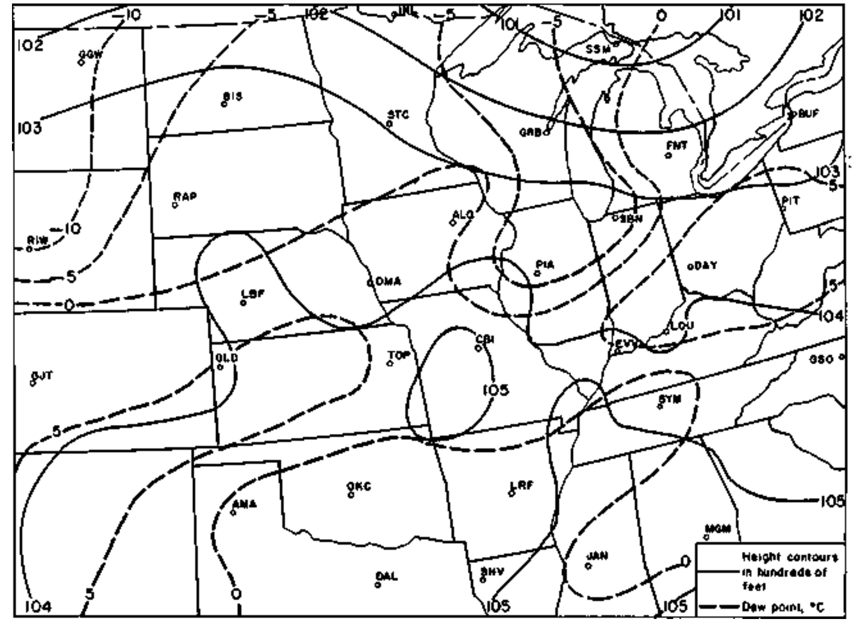


d 0600 CST AUGUST 6, 1959

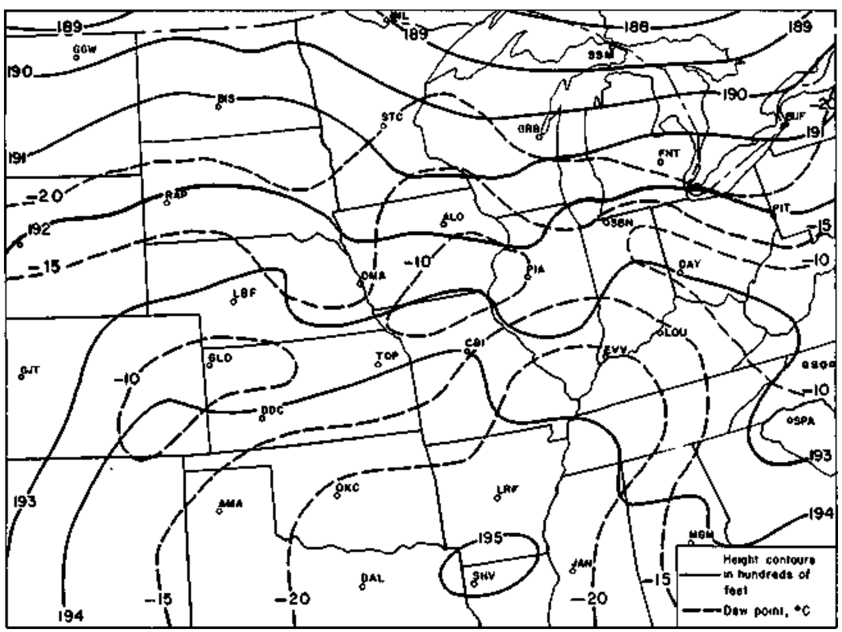
Figure 44. Surface synoptic maps for August 4-6. 1959



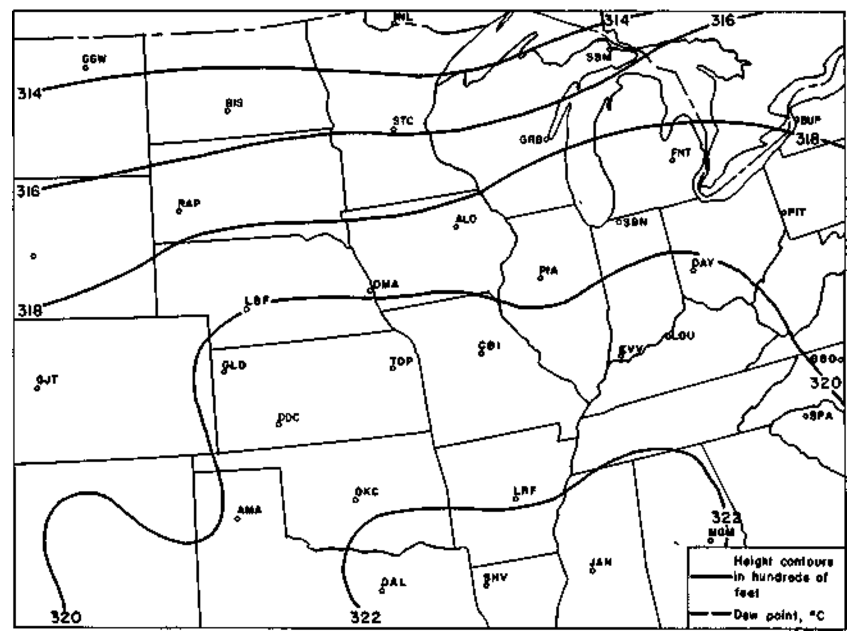
a 850 mb



b. 700 mb

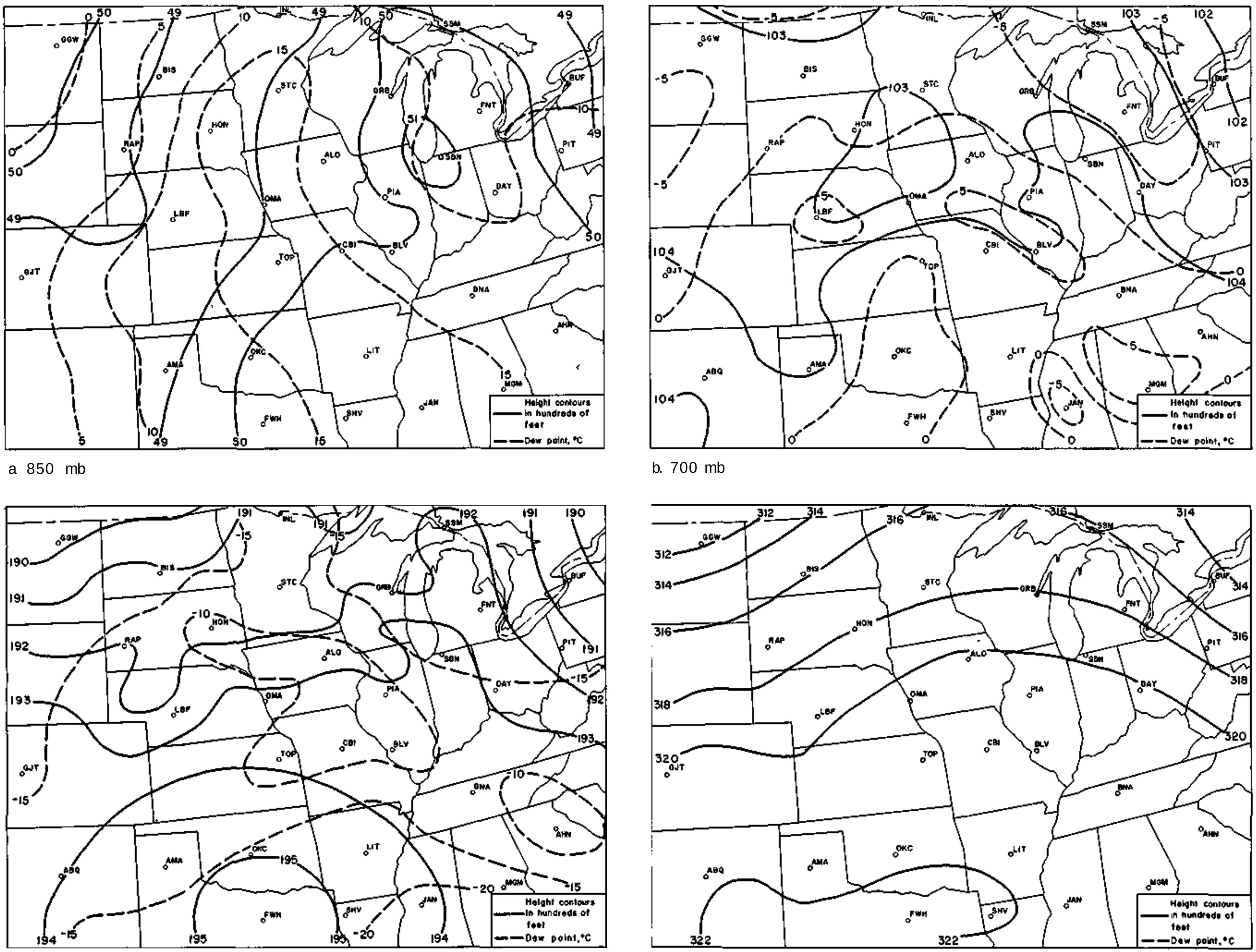


c. 500 mb



d 300 mb

Figure 45. Upper air maps far 0600 CST, August 4, 1959



a 850 mb

b. 700 mb

c 500 mb

d. 300 mb

Figure 46. Upper air maps for 1800 CST, August 5, 1959

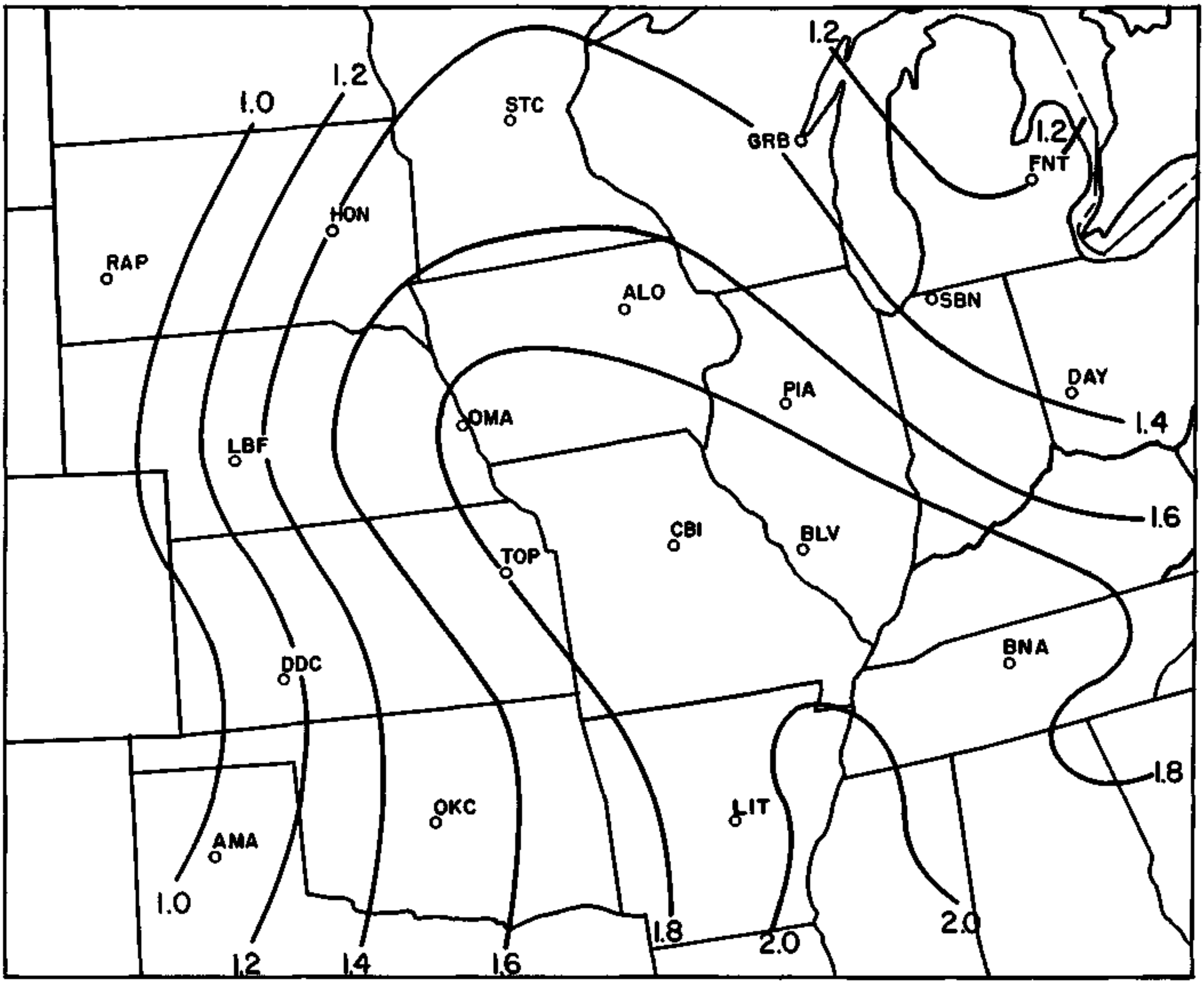


Figure 47. Precipitable water for surface to 400 mb at 1800 CST on August 5, 1959

STORM OF AUGUST 16-17, 1959

On August 16-17, 1959, a severe rainstorm occurred in southern Illinois and bordering states in which amounts in the storm center exceeded 10 inches within 16 hours. Amounts exceeding 6 inches were recorded over 2000 square miles and amounts in excess of 4 inches over a 5000-square-mile area. The core of this storm was centered on a raingage network, which consists of 54 gages in 550 square miles. The network, operated by the State Water Survey, is known as the Little Egypt Network and is located approximately 100 miles southeast of St. Louis in southern Illinois. Twenty-four of the network gages are weighing-bucket recording gages and the rest are standard, 8-inch, nonrecording gages. Data employed in the study include the dense raingage network data, synoptic weather data, radar observations, U. S. Weather Bureau rainfall data, 50 rainfall measurements from the network of nonrecording raingages operated by Southern Illinois University, and 200 field survey measurements of rainfall obtained by Water Survey personnel. Major emphasis has been placed upon analysis of the Little Egypt Network data which provided details on the storm characteristics that are rarely available for such storms. Figure 48 shows the storm isohyetal pattern. The outline of the Little Egypt Network is shown in the center of the storm.

Radar observations of the storm were made with the CPS-9 radar set. The center of the August 16-17 storm was located approximately 140 to 150 miles south of the radar station. In addition to the CPS-9 observations, radar plots of storm echo locations which were prepared by the U. S. Weather Bureau from their national radar network were obtained to aid in the storm analysis.

Isohyetal Patterns

An isohyetal map for the entire storm period is shown in Figure 48. All of the storm rainfall occurred in a 24-hour period beginning at noon on August 16. Within the core of the storm approximately 95 percent of the rainfall occurred in a 16-hour period from 1700 CST on the 16th to 0900 on the 17th, and about 80 percent in the 12 hours from 2100 to 0900. The nearly W-E orientation of the rainfall pattern and the tight rainfall gradients near the storm center are typical of severe rainstorms in Illinois.

Figure 49 shows the isohyetal patterns for the maximum 3-hour, 6-hour, and 12-hour periods of rainfall over the entire storm area. These were obtained by the isopercentile map technique described in a previous Water Survey report.[5] These peak period maps were used to obtain area-depth relations for incremental periods within the storm.

Figure 50 shows the storm total rainfall pattern on the Little Egypt Network on a larger scale than in Figure 48. Reference to Figure 50 shows that the lowest network value of 5.58 inches occurred at Gage P, 9 miles southeast of the highest value, 10.58 inches, at Gage K. The major E-W core across the network was the result of the maximization of several individual rainstorms in this general area. Figure 51 shows the isohyetal patterns for the maximum 1-hour, 2-hour, 3-hour, 6-hour, and 12-hour periods of rainfall on the network. These patterns were well defined by the 24 recording gages in the 550-square-mile area, and provide excellent data on storm rainfall variability and area-depth relations in heavy rainstorms over a small basin. Approximately 30, 46, and 80 percent of the total network rainfall occurred in the maximum 3-hour, 6-hour, and 12-hour periods, respectively.

Probability Analysis

Figure 52 illustrates the relative magnitude and intensity of the storm on the Little Egypt Network. In this figure, selected isohyets have been drawn for the 12-hour period of maximum rainfall and labeled in terms of recurrence interval of point rainfall to which each isohyet corresponds. For example, the 50-year line connects points whose 12-hour rainfall was of the magnitude to be expected once in an average 50-year period at these points; therefore, the 50-year line also encloses the estimated area which experienced rainfall amounts that should not be exceeded more than once in 50 years. An area of approximately 100 square miles through the central region of the network of 550 square miles experienced 12-hour amounts which exceed the 100-year expectancy, based upon the studies of Huff and Neill.[6]

Table 12 provides further information on the relative intensity of the storm on the Little Egypt Network for peak periods of 1 to 24 hours in the storm. In this table, the portion of the 550 square miles which received rainfall equalling or exceeding that to be expected for average recurrence intervals of 2 to 100 years is given. Thus, for the maximum 2-hour period of rainfall, all of the area received amounts equalling or exceeding the 2-year frequency value, while 480, 280, and 45 square miles had amounts which equalled or exceeded 5-year, 10-year, and 25-year recurrence-interval values, respectively. The data in Figure 52 and Table 12 are based upon the maximum peak periods of rainfall at individual points, and these periods did not necessarily occur at the same time throughout the network; however, the 12-hour and 24-hour maximum period's were the same at all points in the 550-square-mile network. Table 12 shows that the relative intensity of the storm was considerably greater for 12-hour and 24-hour periods than for shorter durations; that is, there was more area which experienced longer recurrence-interval values.

Table 13 shows relations for the entire storm zone in Illinois for periods of 12 and 24 hours. Shorter period relations could not be determined with the limited amount of recording gage data.

The recurrence interval of areal mean rainfall on the 550 square miles comprising the Little Egypt Network was determined for 3-hour to 24-hour periods (Table 14), based upon State Water Survey and U. S. Weather Bureau studies.[6, 9] The values were derived for the network average rainfall over a specific time period; thus, the 3-hour period with the highest mean rainfall was 0000-0300 CST on the 17th with a mean rainfall of 2.36 inches, and this value is expected to occur on an average of once in 15 years. Table 14 also illustrates the greater relative intensity of the storm with increasing duration of rainfall, the 12-hour to 24-hour mean amounts having considerably longer recurrence intervals than the 3-hour and 6-hour average values.

Characteristics of Rainfall Distribution

Figure 53 shows a mass curve of mean rainfall for the Little Egypt Network and mass curves for 2 gages in the network. These curves are based on hourly rainfall amounts. Location of Gages G and W is shown in Figure 50. Figure 54 illustrates the time distribution of mean hourly rainfall over the network. These figures show the typical characteristics of such storms, consisting of a number of bursts or individual showers during the total storm period. Figure 54 indicates five bursts with periods of 3 to 4 hours between maximization of bursts. The heaviest bursts occurred near midnight and in the early forenoon of the 17th. The burst (intensity increase) at 0500 CST is minor, but recognizable on Figure 54. This burst was produced by a shower in the northeast section of the network. Gage G in Figure 53 shows the presence of this burst. Since the Little Egypt Network was within the storm core and Figure 53 and 54 are based upon a dense network of recording gages, the curves should accurately represent the distribution characteristics of the rainfall at the storm center.

TABLE 12

RECURRENCE INTERVAL OF MAXIMUM RAINFALL AMOUNTS ON LITTLE EGYPT NETWORK, AUGUST 16-17, 1959

Duration (hours)	Area (sq. mi.) with rainfall equalling or exceeding given recurrence-interval value (yrs.) 2	5	10	25	50	100
1	350	160	70	25	--	--
2	550	480	280	45	10	--
3	550	550	370	110	--	--
6	550	550	520	260	20	--
12	550	550	520	400	290	80
24	550	550	550	510	360	60

TABLE 13

RECURRENCE INTERVAL OF MAXIMUM RAINFALL AMOUNTS, ILLINOIS, AUGUST 16-17, 1959

Duration (hours)	Area (sq. mi.) with rainfall equalling or exceeding given recurrence-interval value (yrs.) 2	5	10	25	50	100
12	4400	3350	2500	1600	1080	250
24	6050	4150	3100	1570	820	150

TABLE 14

RECURRENCE INTERVAL OF MEAN RAINFALL ON LITTLE EGYPT NETWORK, AUGUST 16-17, 1959

Duration (hours)	Time (CST)	Mean rainfall (inches)	Recurrence interval (years)
3	0000-0300	2.36	15
6	2300-0500	3.61	25
12	2100-0900	6.28	100
18	1500-0900	7.75	100
24	1200-1200	7.83	100

Depth-Duration-Area Relations

Area-depth relations for the entire storm area for periods of 3, 6, 12, and 24 hours are shown in Table 15. Table 16 presents area-depth relations on the Little Egypt Network for maximum rainfall periods of 1, 2, 3, 6, 12, and 24 hours, while Table 17 provides hourly data throughout the major portion of the storm from 1600 to 0900 CST. Table 18 shows the time distribution of mean rainfall within the core of the storm on the Little Egypt Network. In this table, the percent of the total storm rainfall is given for selected areas within the storm core for peak rainfall periods of 1 to 12 hours. Thus, within the 100 square miles having the heaviest rainfall during the total storm period, 22 percent of the total storm rainfall occurred within the maximum 1-hour period, 40 percent in the maximum 3-hour period, and 87 percent in the heaviest 12-hour period.

Antecedent Rainfall

The distribution of rainfall for 5-day and 10-day periods preceding the August 16-17 storm was determined since heavy antecedent rainfall would accentuate the flood-producing capabilities of the storm. Isohyetal maps are presented in Figures 55 and 56, based on U. S. Weather Bureau data. Figure 55 indicates very little rainfall during the 5-day period preceding the storm in southern Illinois. The 10-day map shows scattered areas of heavy rainfall along the northern, eastern, and southern edges of the storm region, but little along most of the storm core. Normal 5-day and 10-day rainfall amounts during this period in the region of the storm center are 0.65 inch and 1.30 inches, respectively.

Synoptic Weather

The surface synoptic map for 1800 CST on August 16, near the start of the storm, showed a strong flow of moist maritime tropical air over southern Illinois (Fig. 57). The isobaric pattern indicated a relatively steep gradient, with a weak ridge through the storm region and a trough over the Ozarks to the southwest. Dew points were 70 to 72°F and air temperatures in the upper 70's. The nearest front to the storm area was located approximately 400 miles to the west. Radar and weather station observations indicated widespread thunderstorm activity over central and southern Illinois and adjoining states.

WSW flow at 35 knots over the southern portion of Illinois was indicated on the 850-mb chart for 1800 CST, August 16 (Fig. 58). A weak trough in the contour pattern was oriented NNW-SSE through the storm region. A relatively dry tongue existed to the west of the storm region. Otherwise, the dew point gradient was quite flat over Illinois and adjacent states. The dry tongue over Missouri separated moister regions to the west, in advance of the cold front, and to the east over southern Illinois. Upper air analysis was aided considerably by supplementary RAOB data from mobile stations at Scott Field, Illinois, South Bend, Indiana, and Waterloo, Iowa.

TABLE 15

DEPTH-DURATION-AREA DATA, ENTIRE STORM AREA, AUGUST 16-17, 1959

Storm period (hours)	Average depth (in.) for given area (sq. mi.)									
	25	50	100	200	500	1000	2000	5000	10,000	20,000
3	4.0	3.8	3.7	3.5	3.1	2.7	2.3	1.6	1.1	---
6	5.1	5.0	4.8	4.7	4.3	4.0	3.6	2.9	2.3	1.6
12	9.3	9.1	8.8	8.4	7.8	7.0	6.2	4.8	3.5	2.4
24	10.3	10.1	9.8	9.5	8.8	8.2	7.3	5.9	4.5	3.5

TABLE 16

DEPTH-DURATION-AREA DATA, LITTLE EGYPT NETWORK, AUGUST 16-17, 1959

Storm period (hours)	Average depth (in.) for given area (sq. mi.)									
	1	5	10	25	50	100	200	300	400	550
1	2.92	2.81	2.71	2.54	2.33	2.04	1.67	1.36	1.15	0.92
2	4.30	4.20	4.08	3.87	3.65	3.30	2.85	2.50	2.17	1.77
3	4.45	4.35	4.25	4.12	3.96	3.72	3.37	3.12	2.80	2.36
6	4.98	4.88	4.80	4.68	4.52	4.34	4.08	3.90	3.75	3.61
12	9.70	9.45	9.28	8.96	8.60	8.15	7.52	7.10	6.68	6.28
24	10.70	10.55	10.40	10.15	9.85	9.40	8.90	8.55	8.15	7.83

TABLE 17

HOURLY AREA-DEPTH DATA, LITTLE EGYPT NETWORK, AUGUST 16-17, 1959

Hour ending (CST)	Average depth (in.) for given area (sq. mi.) 1	5	10	25	50	100	200	300	400	550
1700	1.10	1.04	1.00	0.93	0.87	0.78	0.63	0 52	0.43	0.32
1800	1.30	1.25	1.20	1.12	1.03	0.92	0.78	0.70	0.62	0.52
1900	0.76	0.72	0.70	0.66	0 61	0.53	0.44	0.36	0.29	0.20
2000	0.47	0.45	0.42	0.40	0.37	0.32	0.26	0.20	0.16	0.12
2100	0.75	0.72	0.70	0.67	0.62	0.55	0.47	0.39	0.32	0.27
2200	1.28	1.23	1.20	1.13	1.04	0.93	0.78	0.65	0.52	0.38
2300	0.36	0.35	0.33	0.31	0.30	0.28	0.24	0.20	0.18	0.16
2400	1.32	1.25	1.18	1.07	0.96	0.78	0.59	0.49	0.42	0.33
0100	2.92	2.81	2.71	2.54	2.33	2.04	1.67	1.36	1.15	0.92
0200	2.17	2.11	2.06	1.97	1.87	1.71	1.50	1.30	1.09	0.85
0300	1.15	1.12	1.09	1.06	1.00	0.92	0.82	0.76	0.68	0.59
0400	1.15	1.09	1.06	1.00	0.92	0.82	0.69	0.58	0.48	0.35
0500	1.33	1.28	1.24	1.17	1.08	0.96	0.81	0.67	0.54	0.37
0600	1.60	1.45	1.37	1.19	1.05	0.94	0.76	0.62	0.49	0.37
0700	1.76	1.69	1.64	1.57	1.46	1.32	1.11	0.97	0.85	0.66
0800	2.41	2.32	2.26	2.13	1.99	1.80	1.52	1.30	1.11	0.87
0900	1.49	1.43	1.38	1.29	1.20	1.05	0.88	0.73	0.60	0.43

TABLE 18

TIME DISTRIBUTION OF AREAL MEAN RAINFALL
LITTLE EGYPT NETWORK, AUGUST 16-17, 1959

Storm period (hours)	Percent of total storm rainfall for given storm period and area (sq. mi.) 1	5	10	25	50	100	200	300	400	550
1	27	27	26	25	24	22	19	16	14	12
2	40	39	39	38	37	35	32	29	27	23
3	42	41	40	40	40	40	38	36	34	30
6	47	46	46	46	46	46	46	46	46	46
12	91	90	89	88	87	87	85	83	82	80

The 700-mb chart for 1800 CST, August 16, showed WSW flow at about 30 knots over southern Illinois (Fig. 59). A slight trough oriented NNW-SSE was evident in this area. Furthermore, the contour pattern indicated that contrasting maritime polar and maritime tropical air masses were meeting over southern Illinois (Fig. 59). A ridge in the dew point pattern was oriented NE-SW through central Indiana, east central and southern Illinois, and southwestward through Missouri and Oklahoma.

The 500-mb chart at 1800 CST showed westerly-flow at approximately 25 knots over southern Illinois (Fig. 60). A slight trough in the contour pattern was indicated over the state, and similar to the 700-mb chart, a dew point ridge extended NE-SW through the storm region. The 300-mb chart indicated WNW flow through the storm region with a wind maximum of 50 to 70 knots extending northeastward from western to northeastern Illinois about 200 miles northwest of the rainstorm center (Fig. 61). The contour pattern indicated divergence in and north of the storm zone.

The precipitable water map for the surface to 400 mb at 1800 CST (Fig. 62) showed a maximum zone with values near 2 inches extending southwestward from Michigan through central Indiana, southern Illinois, southeastern Missouri to Oklahoma. RAOB data indicated the core of the zone of maximum precipitable water extended through the storm zone of southern Illinois. Scott Field, located near the northern edge of the heavy rainfall zone, had a precipitable water content of 1.93 inches for the layer, surface to 400 mb, at the start of the storm. This amount is about 35 percent above normal for August, based upon Water Survey studies. This abnormality was due to excessive amounts ofmoisture above 850 mb, the surface to 850-mb level having a near normal amount. The Showalter stability index of +2 in the storm zone (Fig. 63) at 1800 CST was not indicative of a highly unstable atmosphere.

Radar Analysis

Radar observations with the CPS-9 were made during a portion of the storm. The radar set was turned off for the day at 1930 CST on August 16 during the early part of the storm and not operated again until 0700 CST on August 17, near the end of the storm period. However, sufficient observations were made to reveal some interesting features of the storm, particularly when combined with the macroscale features of the storm revealed by radar reports from the U. S. Weather Bureau network.

Figure 64 shows the CPS-9 portrayal of precipitation within range of the radar set at selected times. In this figure, the concentric circles represent ranges of 50, 100, and 150 nautical miles. Shading of the radar echoes has been employed to identify separate convection systems. At 1230 CST four areas of rainstorms are indicated by the shading of the radar echoes. All lines were moving in a general eastward to southeastward direction, except the echo area on the Ohio River (EVV) which remained relatively stationary. The number and extent of the squall zones shown by the radar at this time indicate that conditions were favorable for thunderstorm development and sustainment over a wide area in Illinois and Indiana. The squall line shown over southern Illinois produced light rainfall as it moved across the southern Illinois storm zone.

Figure 65 shows regions within which echoes were reported by the U. S. Weather Bureau radar network at selected times. The stippled areas represent envelopes of areas in which echoes were widespread but not necessarily contiguous In most cases, over 50 percent of the stippled areas were occupied by echoes. At 1200 CST Figure 65 reveals an area of convective activity extending northward from the Gulf up the Mississippi Valley, broadening over the hill regions of Missouri, southern Illinois, southern Indiana and western Kentucky, and then extending northeastward and eastward into Pennsylvania and New York. Reference to the synoptic weather and radar maps indicates that southern Illinois was in the center of a region of convective activity at that time. The area was lying near the axis of the convective area extending northward from the Gulf, in and north of the hill regions which appeared to be augmenting the activity, and within the path of squall lines moving from the west and northwest.

Four and one-half hours later at 1630 CST, three separate squall zone areas are indicated by the CPS-9 (Fig. 64). The zone over west central Indiana is the same storm system that was located over eastern Illinois at 1230, while the zone through the radar station is the one that was over western Illinois at 1230. The W-E line extending through southern Illinois was first detected about 1500 when it developed slightly south of the position shown at 1630. This development was in the region in which the southern extremity of the squall line to the north had passed earlier. Possibly, this line resulted from intensification of northward-moving cells formed in the hill country to the south and southwest in Illinois and Missouri as they reached an area of increased evaporation, which was produced as clearing followed the passage of the earlier squall line. This W-E squall line is oriented approximately parallel to the southern Illinois storm zone which developed later, and probably represents the initial phase of development of the zone. As observed in a majority of the 10-inch storms studied in Illinois, development took place near the boundary separating a hot, mostly sunny, humid region from a partly cloudy to cloudy, rainy area with somewhat cooler temperatures. Maximum temperatures on August 16 exceeded 90°F in the storm region compared to 75 to 80 degrees in northern Illinois. Sunny conditions prevailed most of the day of the storm except during brief shower periods.

The CPS-9 portrayal 1 hour later at 1730 CST (Fig. 64) shows the southern Illinois squall line merging with the line to the north, while the line to the north also appears about to merge with the line east of it over central Indiana. With the merging of these three squall lines, the heavy storm was underway. The CPS-9 presentation at 1915 CST (Fig. 64) shows conditions shortly before the radar operations were terminated. The merger had been completed by this time. The southern portion of the squall line was drifting very slowly southward while the northern portion was moving eastward at a considerably greater speed.

Referring to Figure 65 again, it is seen that by 1600 CST the Mississippi Valley area of rainstorms had dissipated except near the Gulf as the peak of diurnal heating passed. A region of convective activity was still present over Texas and Oklahoma, and this region was located near the precipitable water axis extending from Michigan to Texas, discussed earlier. Also, the radar reports indicated a decrease in the extent of the activity in the hill regions of southern Illinois and adjacent states with the passage of the diurnal heating peak. A large area of convection extended from western New York southwestward through Illinois to Texas.

By 0100 CST (Fig. 65) the storms were restricted primarily to southern Illinois and adjacent states. A weak squall line was indicated through Iowa, probably initiated by the cold front to the west. This line dissipated as it entered Illinois. The Gulf activity was almost completely dissipated by that time.

The last CPS-9 illustration in Figure 64 shows the radar portrayal at 0815 CST on the 17th, shortly after the radar was turned on. The last heavy burst occurred in the storm zone at this time, after which the whole system moved southward out of the area at a speed of about 10 mph. The Indiana portion of the squall zone was mostly dissipated by that time. Figure 65 for 1000 CST shows the southward drift of the large-scale system associated with the Illinois storm earlier. Redevelopment of the Gulf activity at that time as diurnal heating increased can be noted.

Storm Characteristics

Using data from 18 recording gages in southern Illinois and southeastern Missouri in conjunction with the Little Egypt Network data, an effort was made to trace the rainfall lines through the storm region and surrounding area to obtain information on the origins of these lines and to gain a better understanding of the storm characteristics. Newton and Katz have demonstrated the feasibility of using the hydroclimatic network for this purpose. This approach was dictated by the lack of detailed radar data during a large portion of the storm.

Results of this analysis indicated that 9 lines passed through or near the storm center during the storm period. Most of these lines were detected first in the surface rainfall pattern 75 to 100 miles northwest of the storm center. Using rainfall data, hourly sequence data from Weather Bureau stations in the vicinity, and upper air maps, it appears that these lines formed on the south side of and approximately parallel to a wind maximum found at the 300-mb level. These lines moved toward the rainstorm center at calculated speeds of 12 to 42 mph, with a median value of 27 mph. Most of the lines appeared to move from the NNW. The line speeds decreased greatly in moving through the rainstorm core. The median speed was 10 mph for the 6 lines which passed through the storm center. These lines appeared either to dissipate or to increase considerably in speed upon leaving the storm center.

Analysis of available data suggests that after forming near the wind maximum, the squall lines developed vertically as they moved toward the rainstorm center through the 300-mb divergence area (Fig. 61). As a line approached the rainstorm center, the moisture inflow was increased appreciably upon entering the zone of maximum precipitable water content (Fig. 62) and the precipitation process maximized in this region. With vertical development of the lines as they approached the rainstorm zone, the motion of individual thunderstorms in the line, and consequently the line itself, became increasingly influenced by the higher level winds. As a result, the lines frequently assumed a ENE-WSW orientation by the time they entered the storm zone, and the majority of the individual storms within the line moved nearly parallel to the rainstorm axis, which was orientated from 280 to 100 degrees (Fig. 48). This change in orientation of lines as they entered the storm zone may partially, at least, account for the rapid reduction in line movement. As the line elements maximized over the rainstorm zone, a strong outflow of cold air resulted with rapid development of new cells at the outflow boundary, which produced an apparent increase in line speed beyond the storm zone. As the lines left the rainstorm zone they moved out of the maximum precipitable water region and the 300-mb divergence area, and became less intense and more under the influence of the lower level winds again. With shifting of winds to a more northerly direction and the advent of drier air, the rainstorm zone decreased in intensity and moved southward during the forenoon of the 17th (Fig. 65).

The analysis of data from each recording gage in the network indicated that 6 squall lines crossed the network. The orientation, speed, and direction of movement of these lines is depicted in Figure 66. The line speed varied from 8 to 25 mph with a median value of 10 mph. In Figure 66c the simultaneous occurrence of 2 lines on the network is shown. The third line, enhanced by its interaction with the fourth, produced the 3-hour period of heaviest rainfall on the network, 0000-0300 CST (Figs. 51, 54).

The rainfall patterns for each hour from 1500 CST on the 16th to 1200 on the 17th are shown in Figures 67 and 68. Examination of the heavier individual rainstorms, those in which the hourly rainfall exceeded 0.3 inch, provided an estimate of their direction and speed of movement. The 19 individual rainstorms detected in this 21-hour period were assigned, for identification purposes, lower case letters on the hourly rainfall maps. Within the Little Egypt Network the storms exhibited a wide range of movement, the speed varying from 7 to 25 mph and the direction of movement from 240 to 330 degrees. Part of the variation in motion, at least, is due to development of new cells on the right flank of a line, as pointed out by Newton and Katz/[0] which causes the surface rainstorms to move to the right of the mean upper wind flow, the amount depending upon the rapidity of development on the flank. Other factors which may be an influence are differences in vertical development and mesoscale convergence in the storm zone. The median speed of the individual storms in the rainstorm core was 13 mph with the majority between 10 and 15 mph. The median direction was 280 degrees with the majority between 270 and 290 degrees. The mean wind from 2000 to 30,000 feet at 1800 CST was 250 degrees, 35 mph.

Using mean values obtained by Newton and Katz, individual rainstorms would be expected to move at 275 degrees, 27 mph. The median direction of 280 degrees on the Little Egypt Network compares favorably with these mean values, but the median speed of 13 mph is only about one-half of the expected value. The large reduction in speed of individual rainstorms in the storm core may be due to blocking action on the wind flow by the convection system which was well developed vertically up to a distance of 90 miles to the west, upwind of the speed reduction. The slowing down of the individual storms and lines within the storm core is partially responsible for the heavy amounts recorded. However, strong intensification is indicated also in the storm core, since approximately 5-inch amounts would have occurred without any decrease in speed through the core with the rainfall intensities experienced.

The movement of the rainstorms was compared to the movement of the squall lines with which the storms were associated, except for g and h(Fig. 67), which were not associated with any line. Comparisons of individual storms and their associated lines were made by classifying the lines into three directions of movement, NNW, NW, and WNW. The rainstorm movement was always from a more westerly azimuth than that of the line movement with the angular difference between the directions of the two associated phenomena varying from 18 to 51 degrees depending on the direction of line movement.

Rainfall-Runoff Relations

Two recording streamgages of the U. S. Geological Survey were in operation along the Big Muddy River within the area of the Little Egypt Network during the storm period. These gages and the river are shown on Figure 50. The area drained by the southernmost of the two streamgages (Plumfield), but not by the northern streamgage (Benton), lies largely within the densely-gaged network and is labeled basin A on Figure 48. This fortunate situation permitted a comparison of the storm runoff and rainfall from this basin area. Basin A (Fig. 48) consists of 255 square miles and is comprised almost entirely of rural farmland.

The amount of discharge at the Benton streamgage (Fig. 50) was subtracted from the amount at Plumfield for the period from the time of storm initiation until the river returned to base flow. Base flow for the river at both streamgages was reached by September 1, resulting in a 17-day period, August 16 through September 1, when discharge from the storm was continuing. The total difference in discharge between the two gages, or the total amount of runoff from the 255-square-mile area as computed by using a recession curve extension with a factor of 0.9, was 18,324 second-foot days. This amounts to an average depth of 2.65 inches of water over the basin area. The average rainfall depth calculated for the 255-square-mile area was 6.92 inches. Thus, approximately 38 percent of the rainfall became runoff while the remaining 62 percent went into evaporation and transpiration. Under average conditions, 30 percent of the rainfall in this area of Illinois becomes streamflow. Only one period of very light rainfall occurred over the basin after the storm ended and before September 2, so no significant effect on the amount of runoff can be attributed to other rainfall in the discharge period.

The river hydrographs (Fig. 69) reveal that the peak discharge at the Benton streamgage occurred on August 18, one day after the storm had ended. Peak discharge at Plumfield came on August 20, three days after the storm ended. However, since rainfall north of the Benton gage was much less than in the northern area of the Little Egypt Network (Fig. 48), and since the Benton gage drainage area was less, 498 square miles compared to 753 square miles at Plumfield, the discharge was much more rapid at Benton and makes comparisons of discharge rates difficult. On the peak discharge days, both streamgages passed 16.2 percent of their 17-day total runoff. More than 80 percent of the runoff from the storm at both stations had been discharged by the sixth day after the storm ended.

Summary

On August 16-17, 1959, a severe rainstorm in which amounts exceeded 10 inches in 16 hours occurred in southern Illinois and bordering states. The core of this storm was centered on a raingage network consisting of 54 gages in 550 square miles in southern Illinois. This network provided details on the storm characteristics seldom available in severe rainstorms. Rainfall amounts in the storm center exceeded the 100-year frequencies in this area.

Radar observations indicate that this severe rainstorm was initiated over southern Illinois when a squall line, oriented E-W in extreme southern Illinois and moving slowly northward, merged with a squall line moving southeastward from central Illinois. This merging took place in the region of maximum precipitable water content at that time. The storm was sustained by a series of squall lines which moved into the storm zone during the 16-hour period following the initial merger. Analysis of the dense raingage network data indicated that 6 lines of rainfall swept across the storm core, while analysis of recording raingage data outside the storm core indicated approximately 9 lines occurred within or surrounding the storm region during the storm period. Most of these lines were detected first in the surface rainfall pattern 75 to 100 miles northwest of the storm center. Analysis indicated that the supporting lines probably formed south of and approximately parallel with a 300-mb wind maximum located about 200 miles northwest of the storm core. These lines developed vertically as they moved southeastward toward the storm region and through an area of divergence at the 300-mb level. As these lines approached the storm zone, they entered the region of maximum precipitable water which resulted in maximization of the precipitation process within the storm zone, apparently a zone of wind convergence and cyclonic shear. As the lines entered the storm zone, their speed decreased greatly as they became oriented approximately parallel to the mean upper wind flow. Furthermore, the speed of individual rainstorms within the lines decreased greatly in the storm center, possibly due to blocking action on the winds from the well developed portion of the convection system upwind from the surface storm core. As the lines moved southeastward out of the storm zone, they left the region of maximum precipitable water content and the upper level divergence field, and gradually dissipated. The storm ended when the zone of maximum moisture content drifted slowly southward, the upper winds shifted to a more northerly direction, and drier air moved into southern Illinois during the forenoon of August 17.

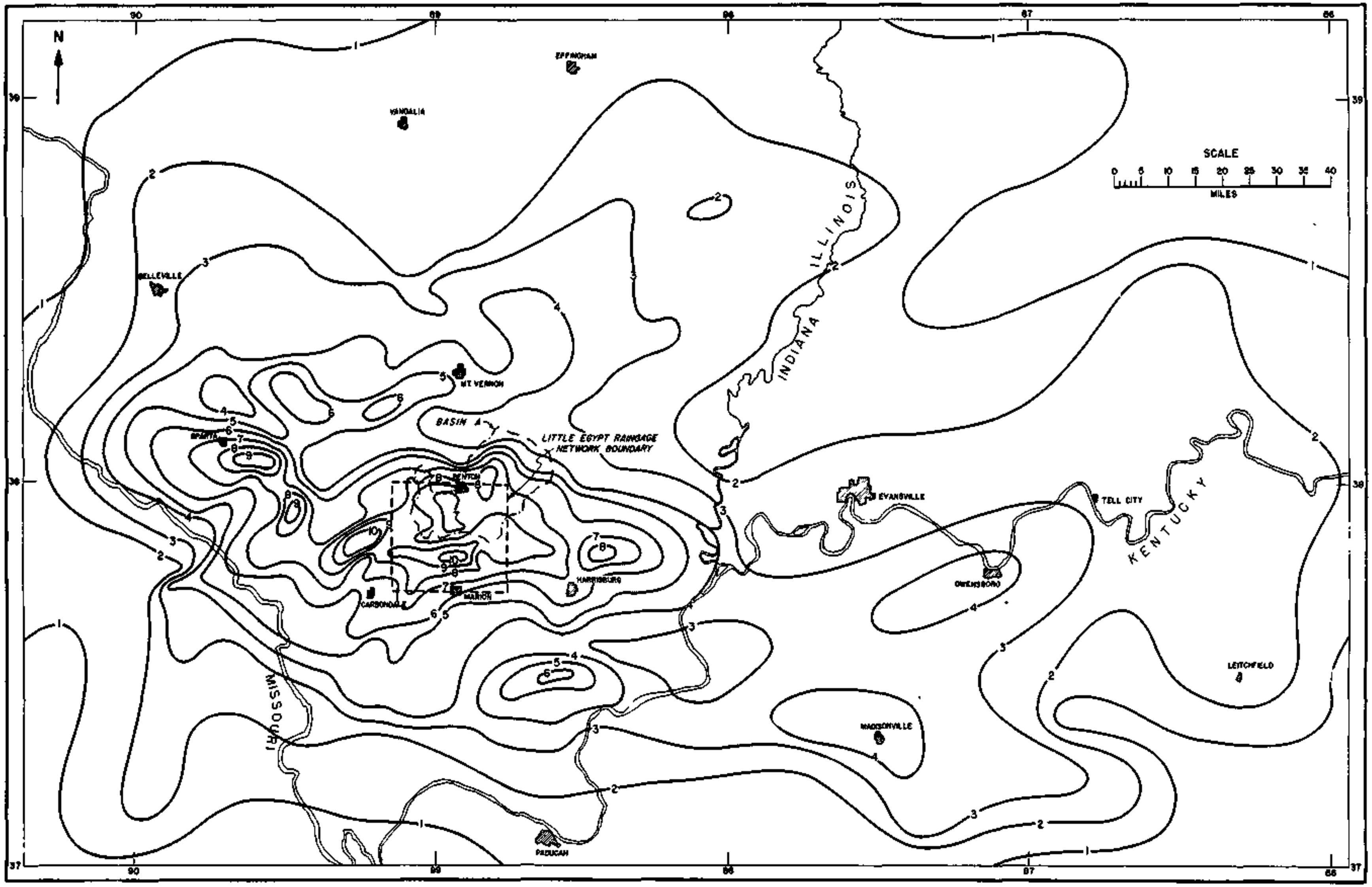
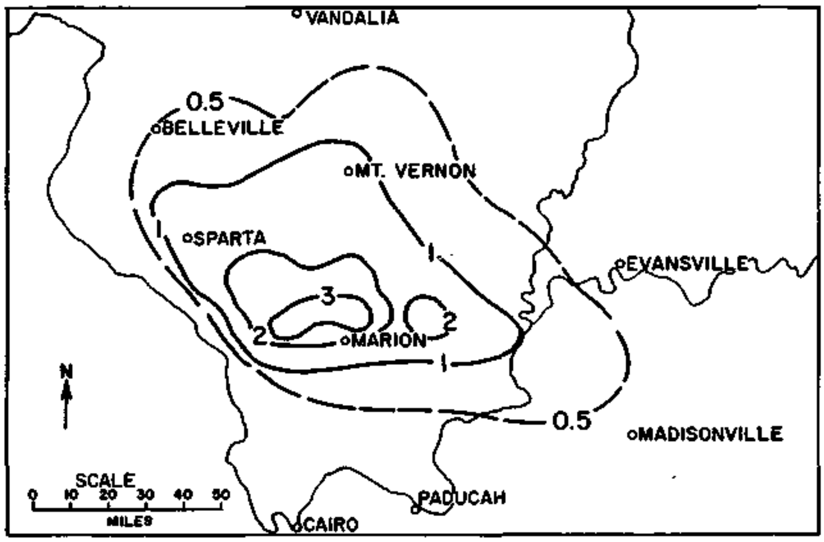
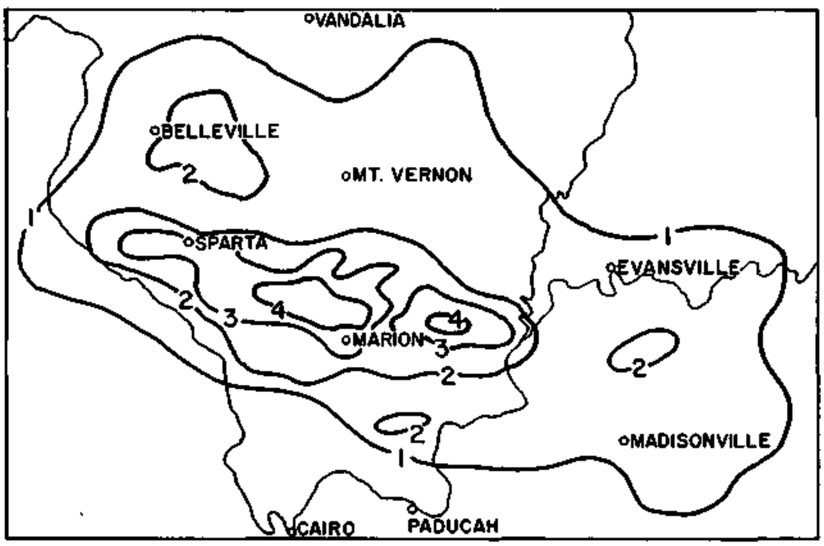


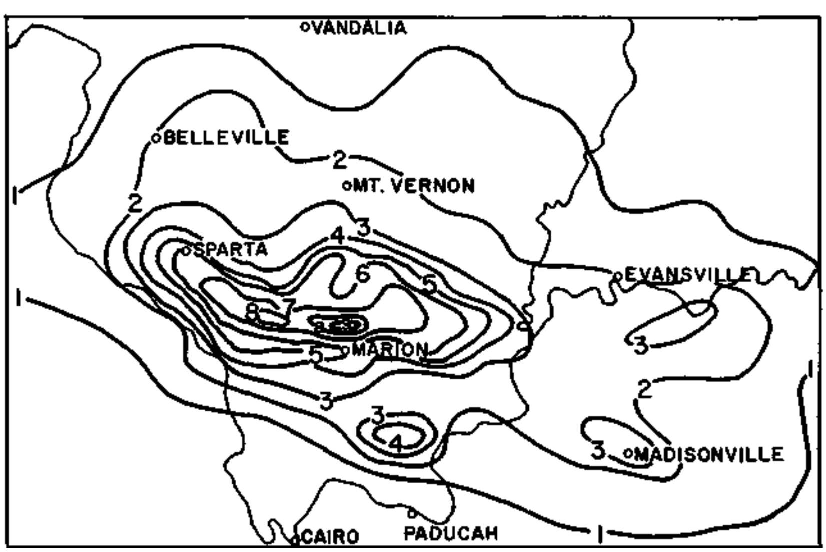
Figure 48. Total storm rainfall for August 16-17, 1959



a. MAXIMUM 3-HOUR RAINFALL, 0000-0300 CST



b. MAXIMUM 6-HOUR RAINFALL, 2300-0500 CST



c. MAXIMUM 12-HOUR RAINFALL, 2100-0900 CST

Figure 49. Maximum 3-, 6-, and 12-hour rainfall maps, August 16-17, 1959

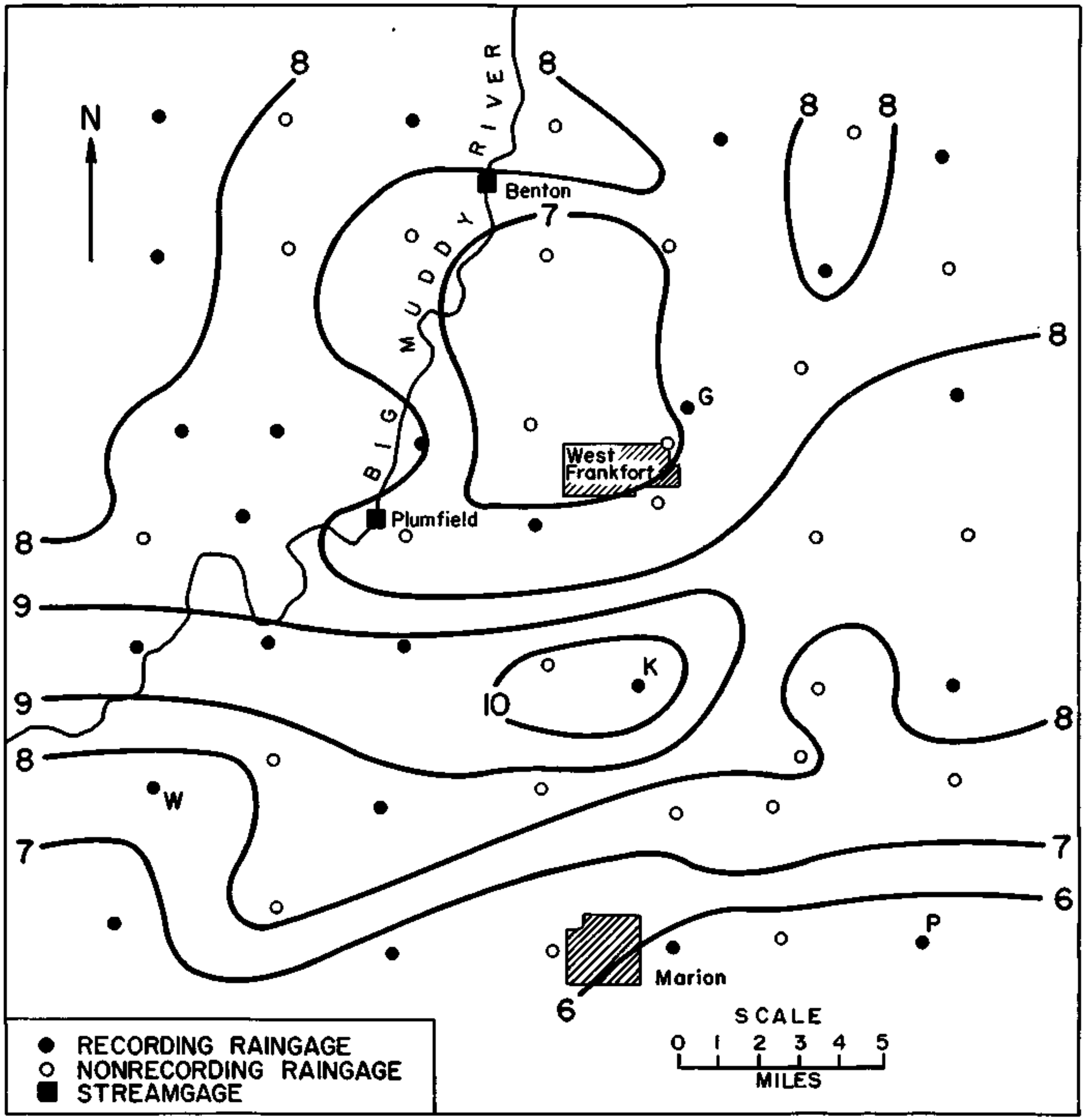
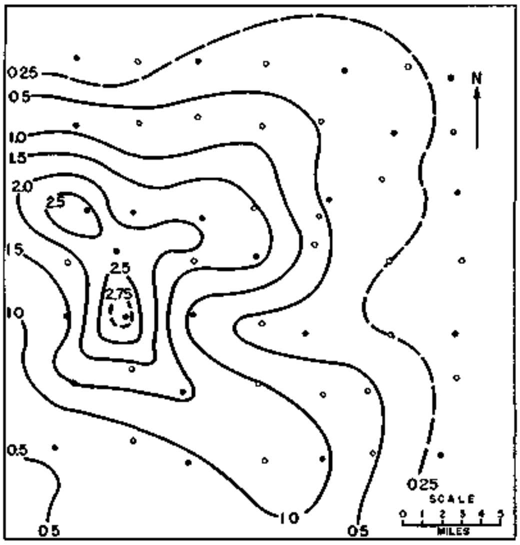
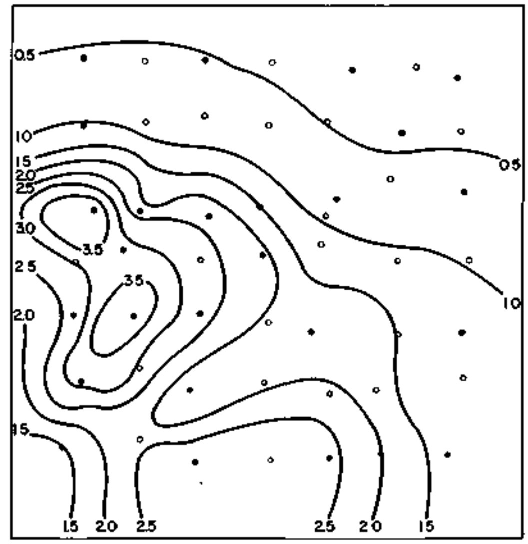


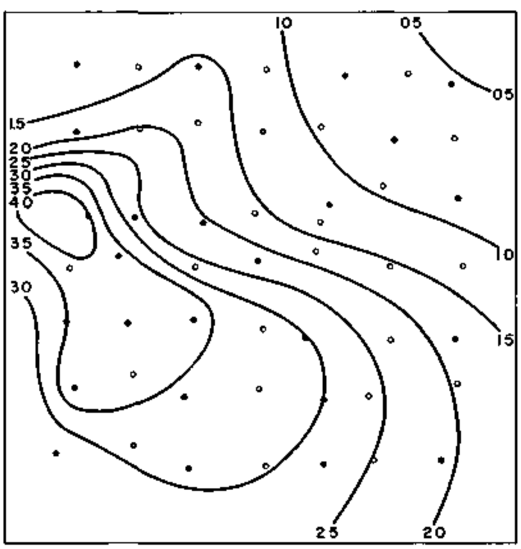
Figure 50. Total storm rainfall. Little Egypt Network, August 16-17, 1959



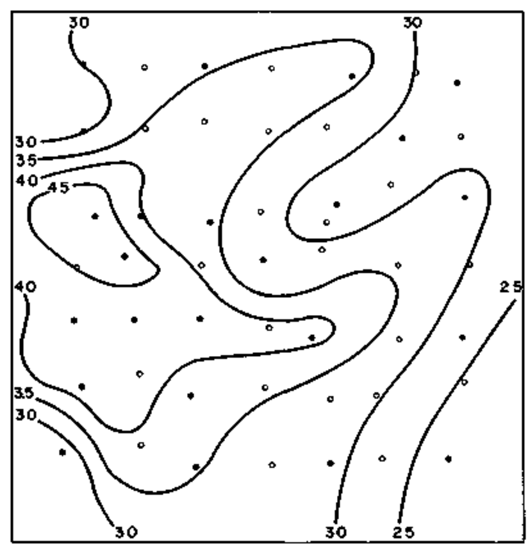
a MAXIMUM I-HOUR RAINFALL



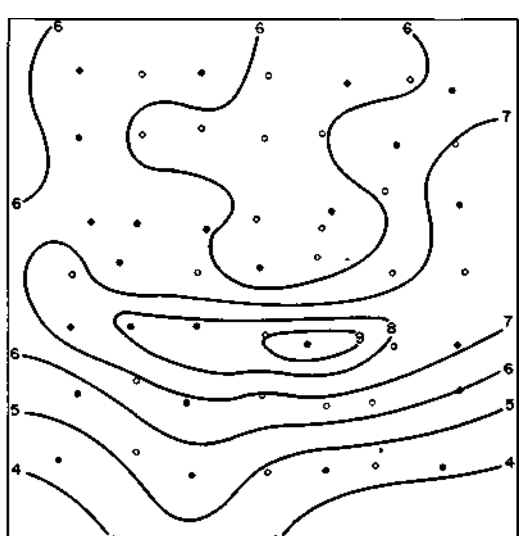
b. MAXIMUM 2-HOUR RAINFALL



c MAXIMUM 3-HOUR RAINFALL



d. MAXIMUM 6-HOUR RAINFALL



e. MAXIMUM 12-HOUR RAINFALL

Figure 51. Maximum rainfall periods on Little Egypt Network, August 16-17, 1959

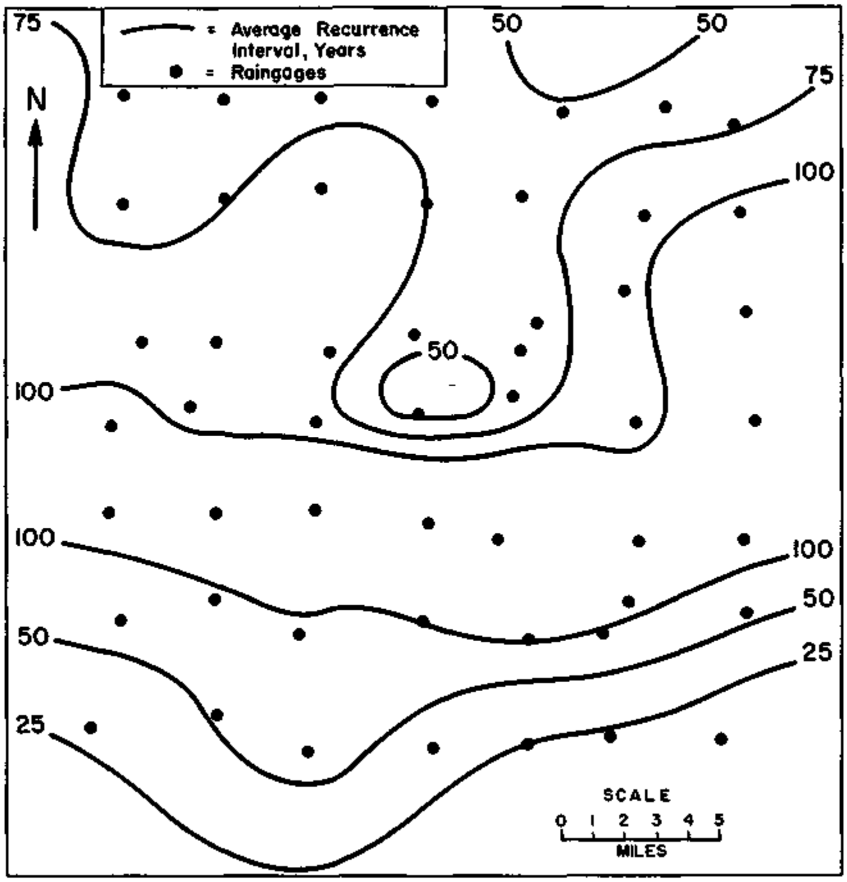


Figure 52. Average recurrence interval of maximum 12-hour rainfall on Little Egypt Network, August 16-17, 1959

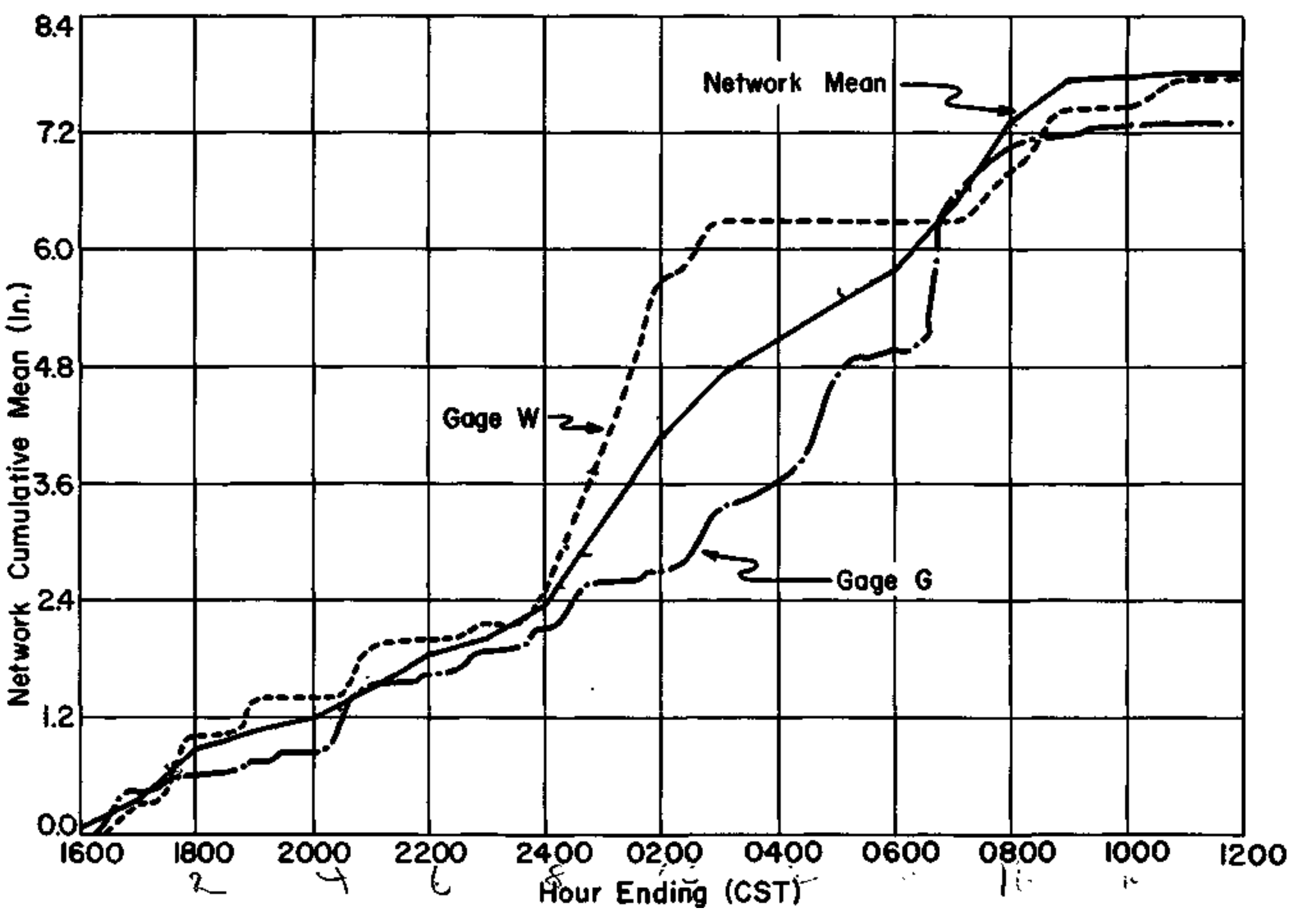


Figure 53. Mass curves for Little Egypt Network based on hourly rainfall, August 16-17, 1959

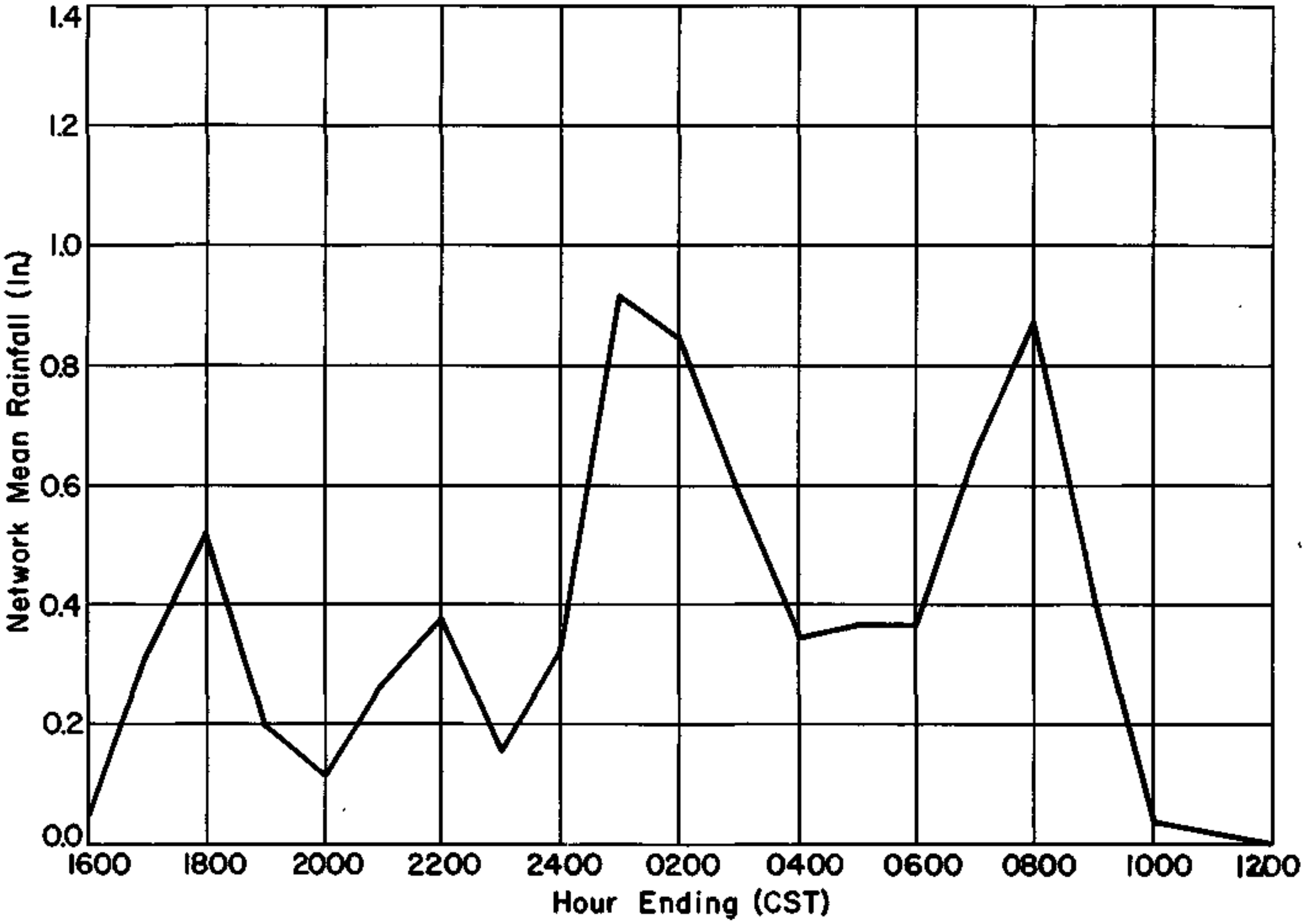


Figure 54. Time distribution of hourly rainfall, Little Egypt Network, August 16-17, 1959

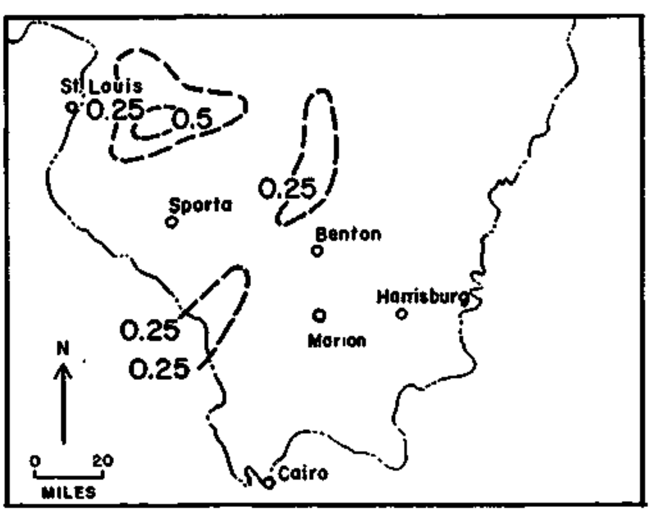


Figure 55. Total rainfall for August 11-15, 1959

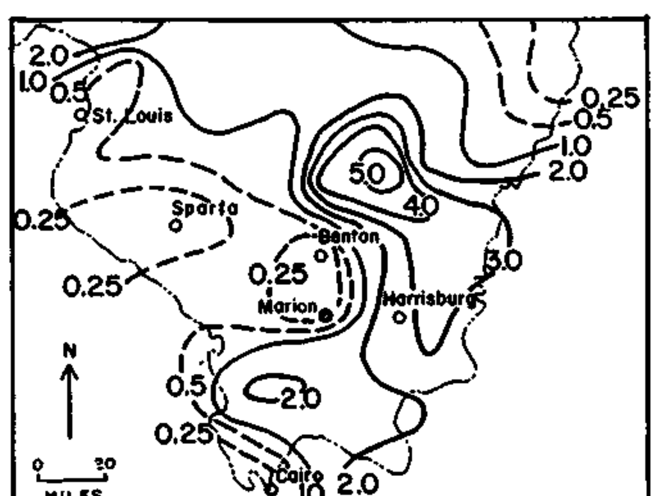


Figure 56. Total rainfall for August 6-15, 1959

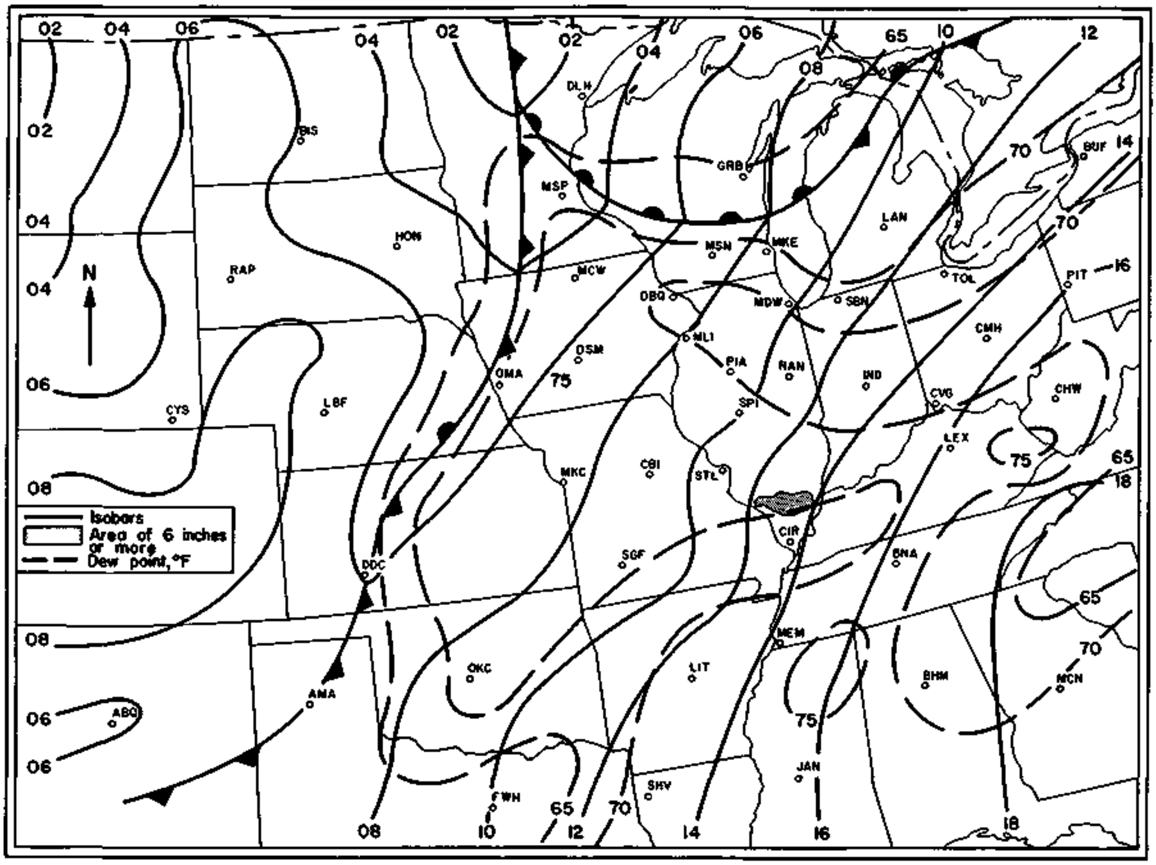


Figure 57. Surface synoptic map at 1800 CST on August 16, 1959

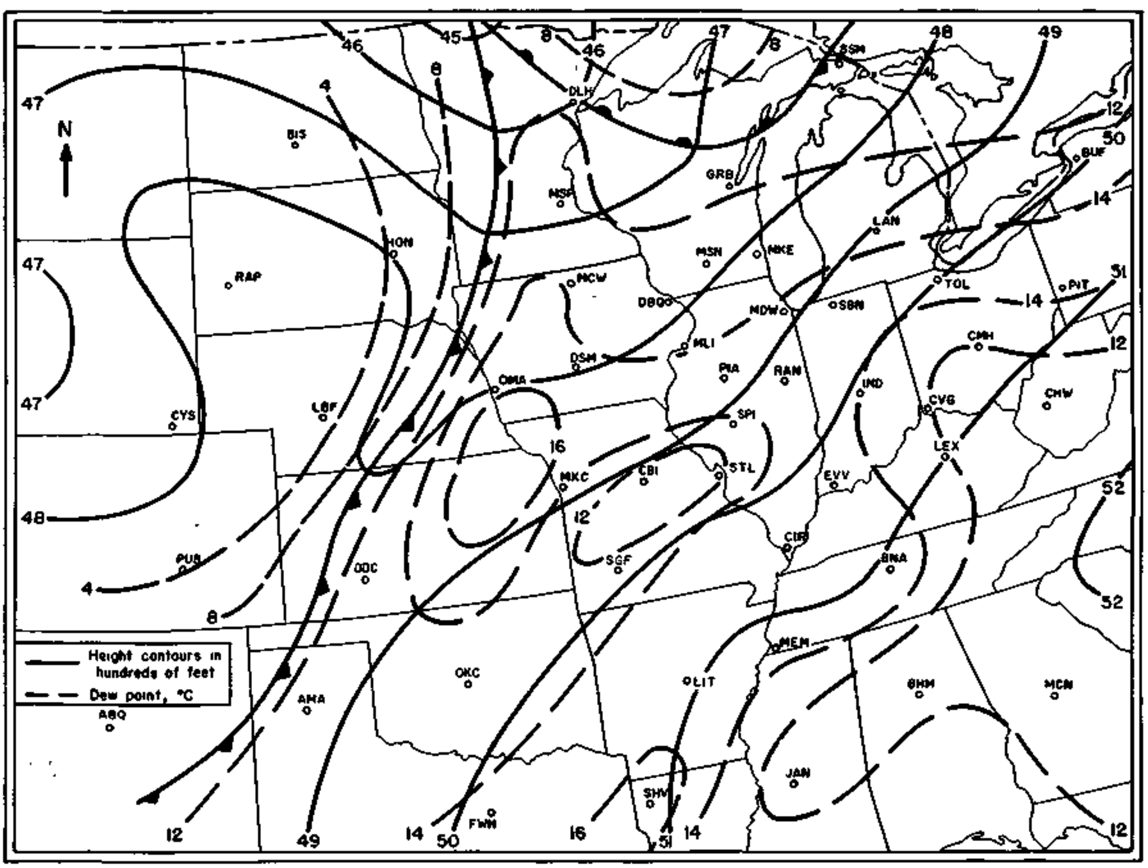


Figure 58. 850-mb map at 1800 CST on August 16, 1959

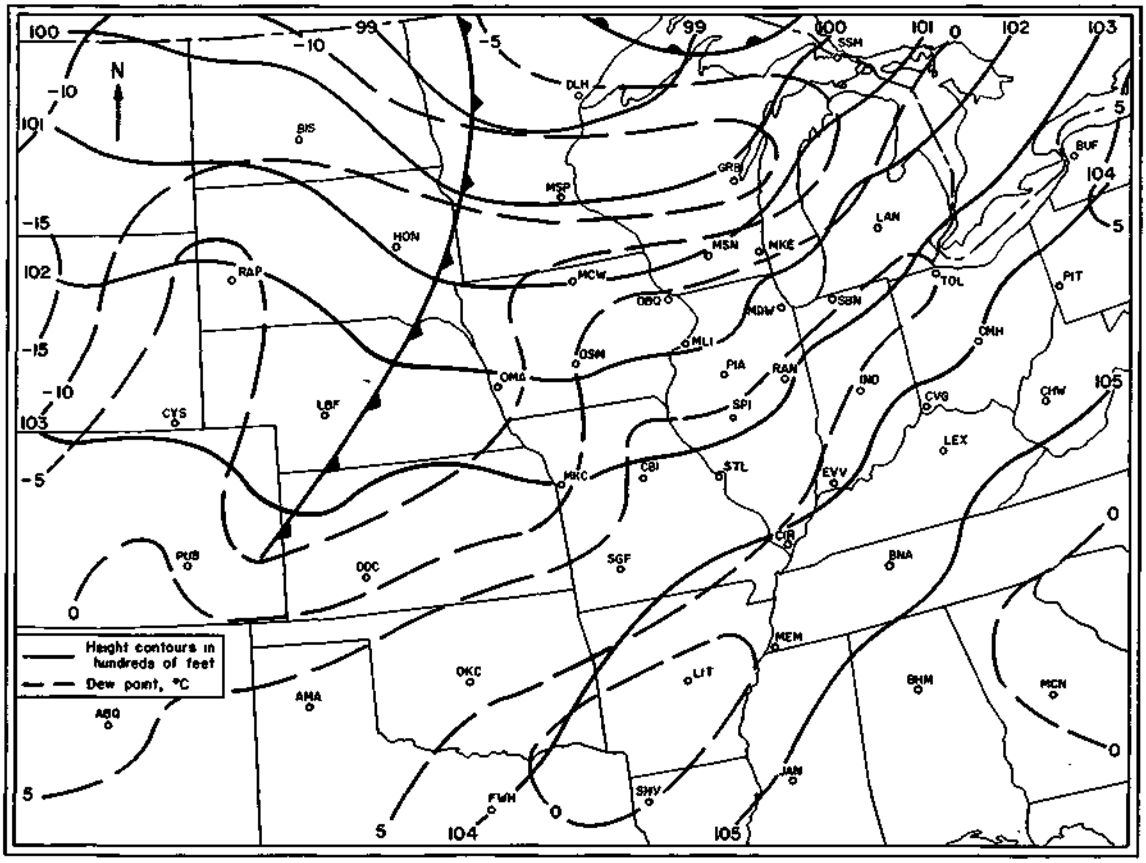


Figure 59. 700-mb map at 1800 CST on August 16, 1959

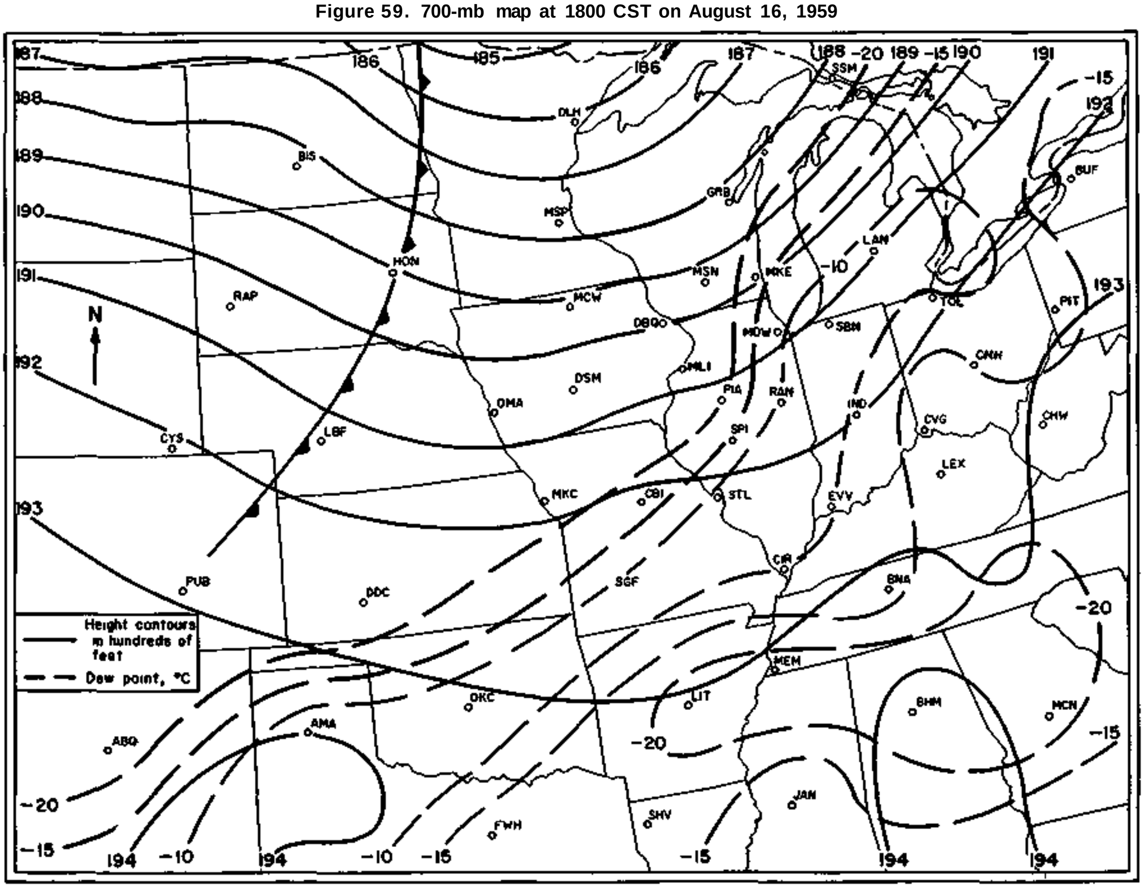


Figure 60. 500-mb map at 1800 CST on August 16, 1959

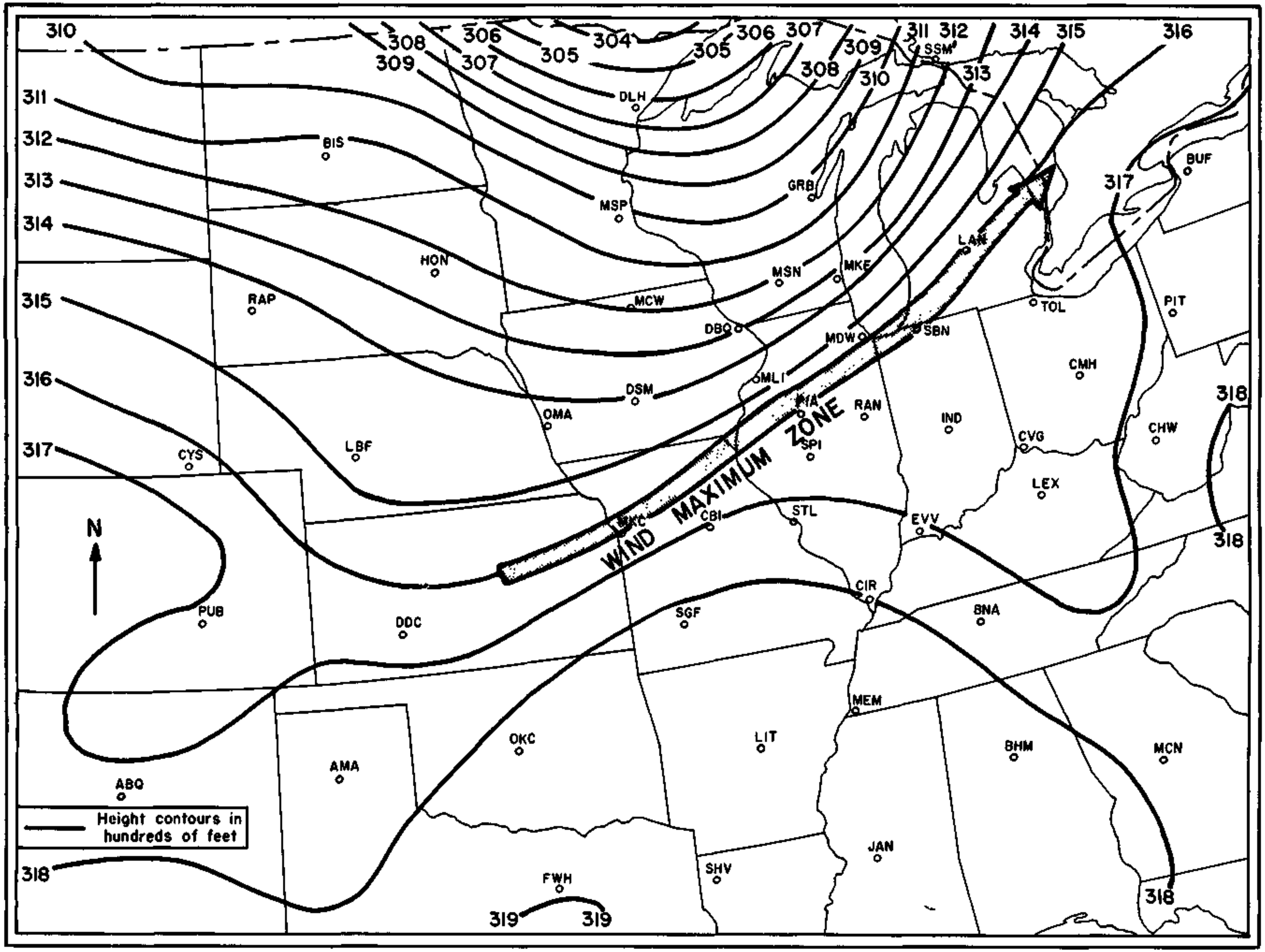


Figure 61. 300-mb map at 1800 CST on August 16, 1959

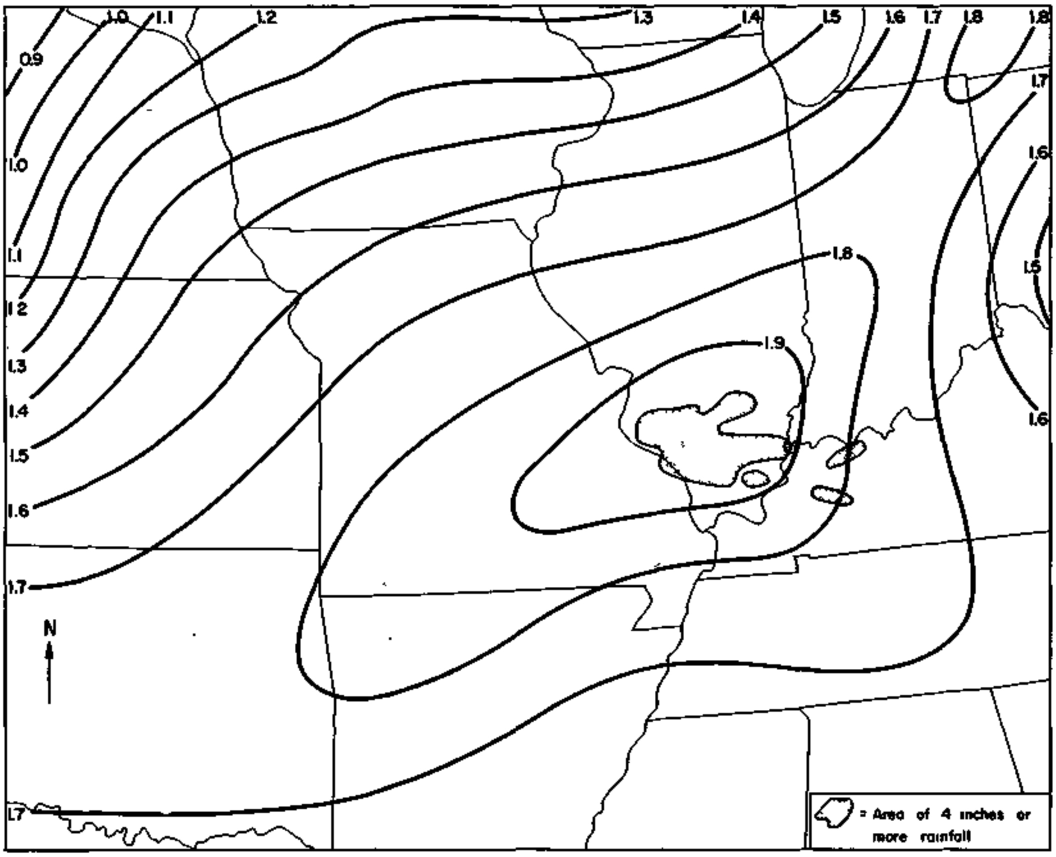


Figure 62. Precipitable water for surface to 400 mb at 1800 CST, August 16, 1959

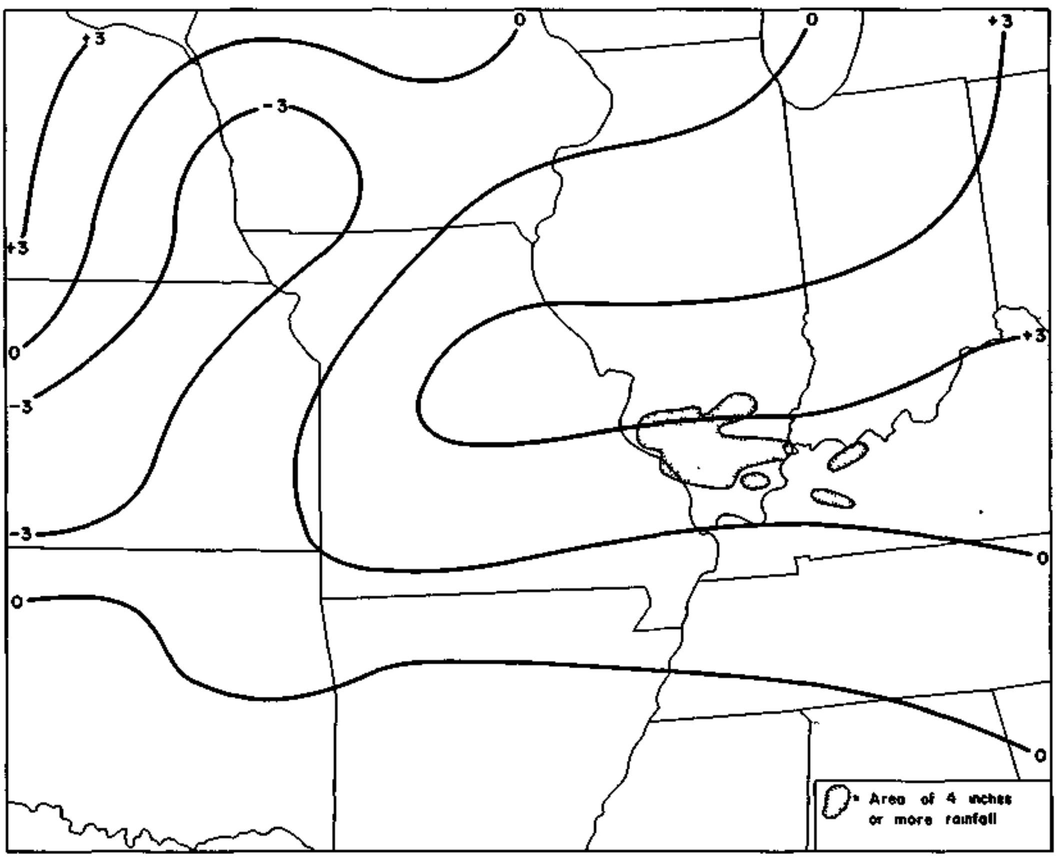


Figure 63. Showalter stability index at 1800 CST, August 16, 1959

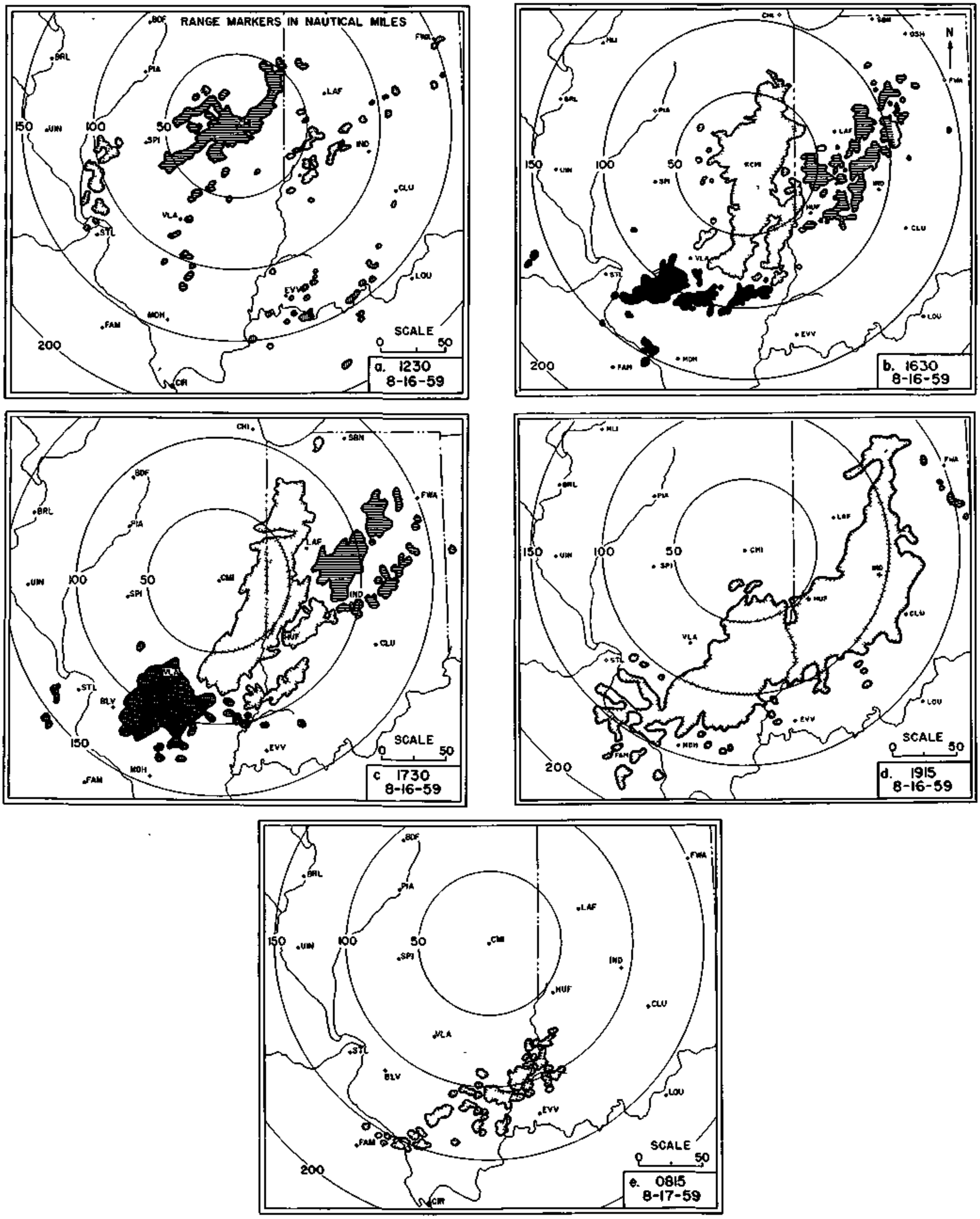


Figure 64. CPS-9 radar echoes on August 16-17, 1959

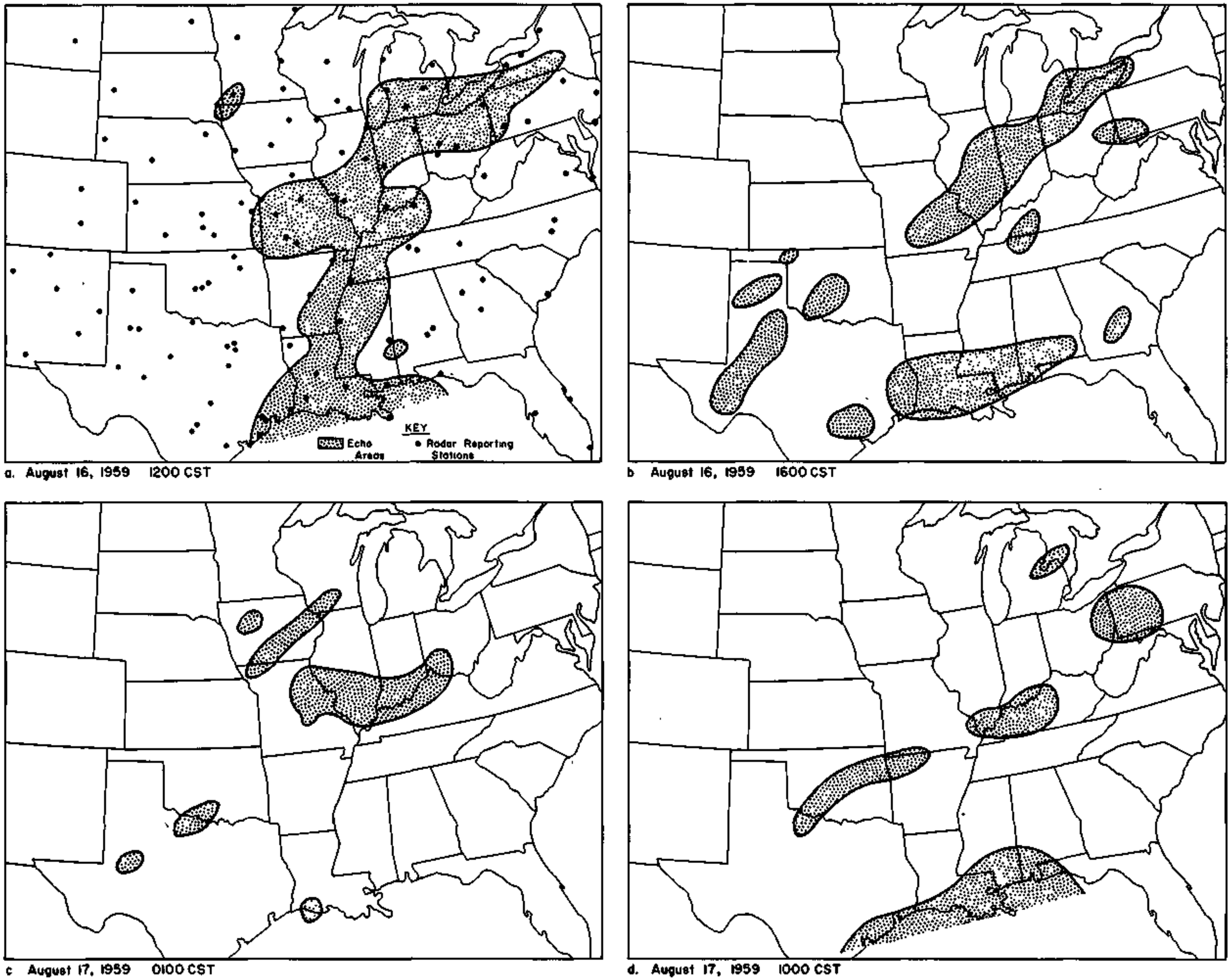


Figure 65. Echo areas indicated by U. S. Weather Bureau radar network on August 16-17, 1959

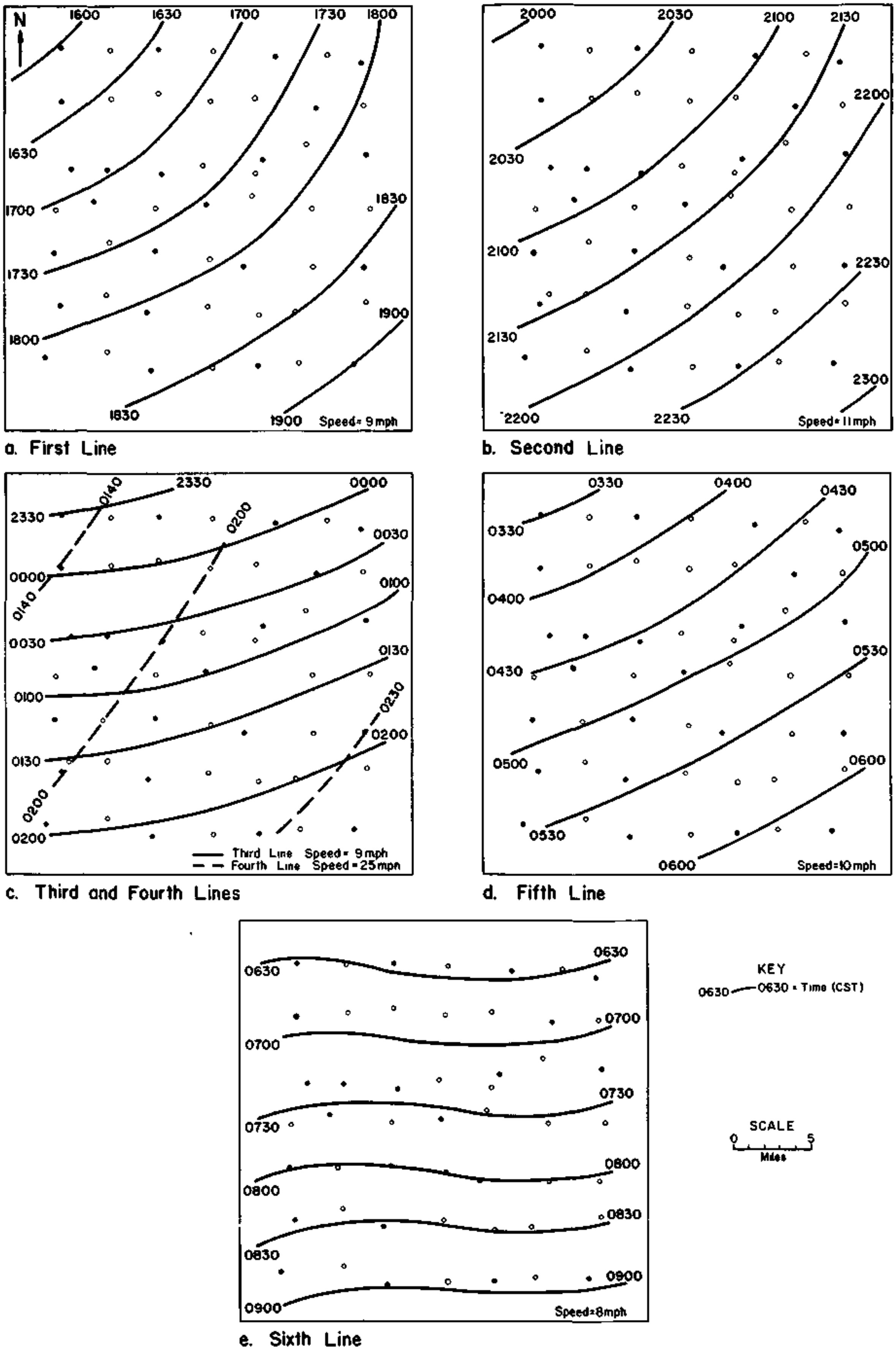


Figure 66. Squall line movement across Little Egypt Network, August 16-17, 1959

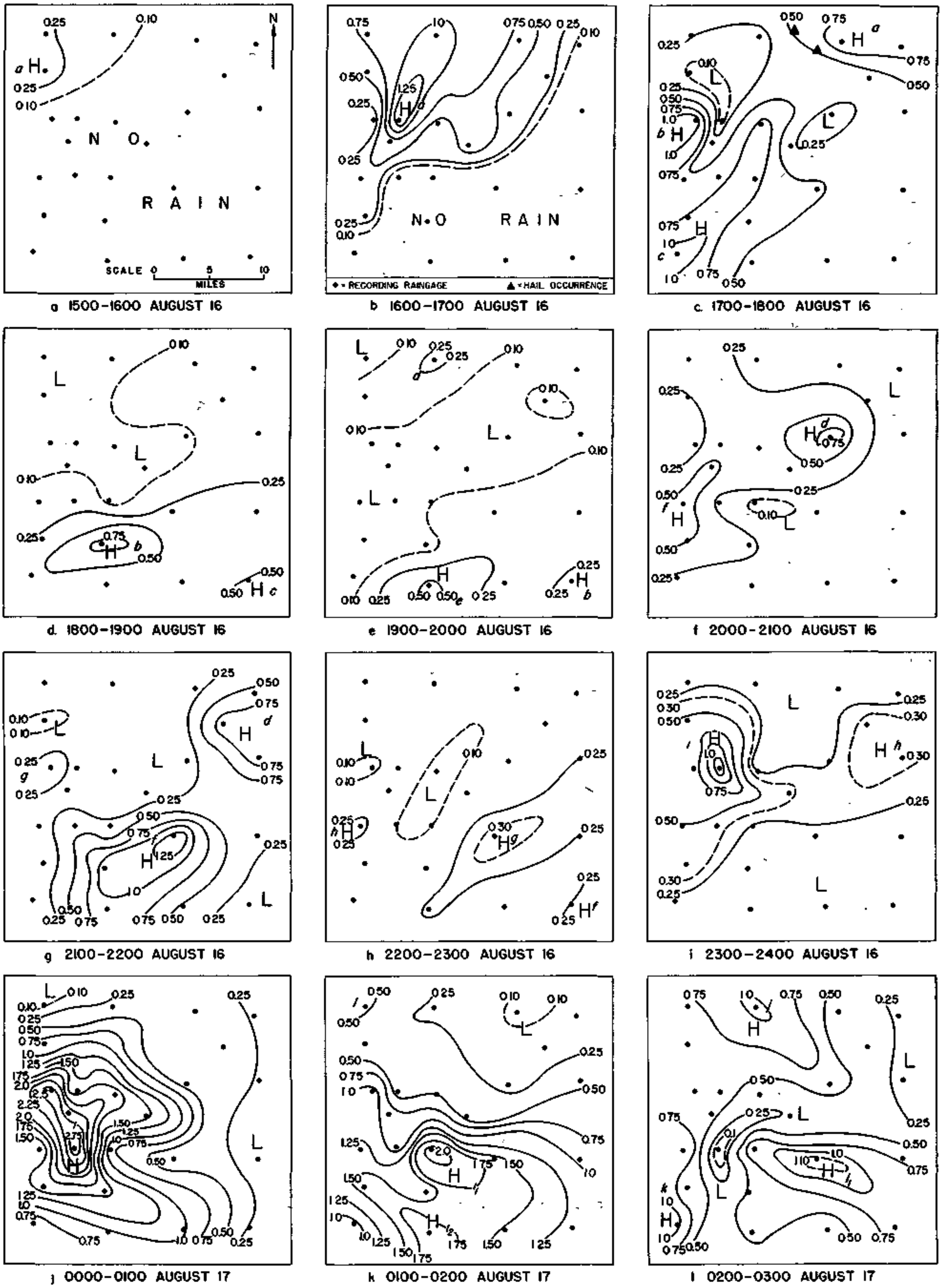


Figure 67. Hourly rainfall maps for August 16-17, 1959

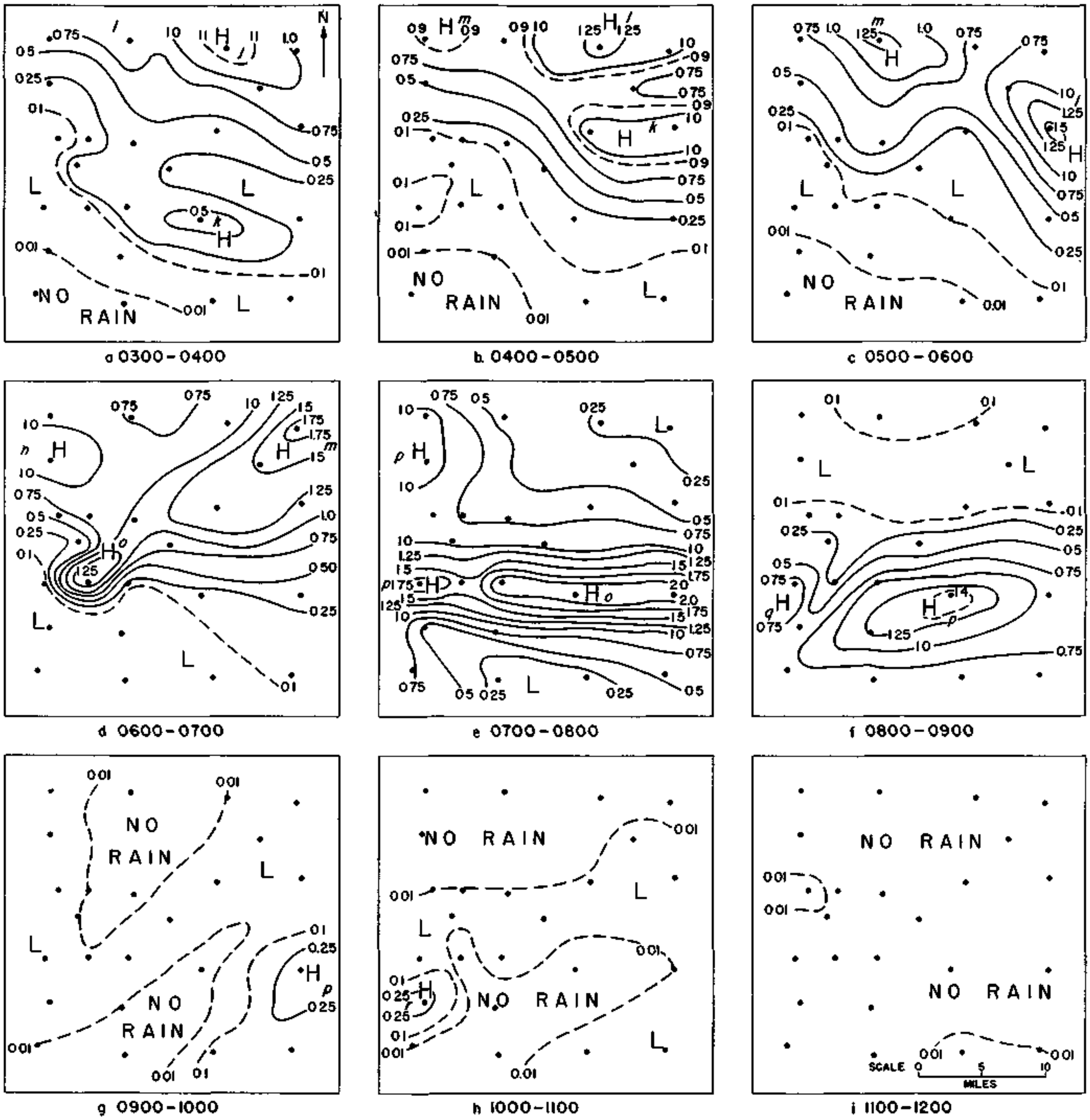


Figure 68. Hourly rainfall maps for August 17, 1959

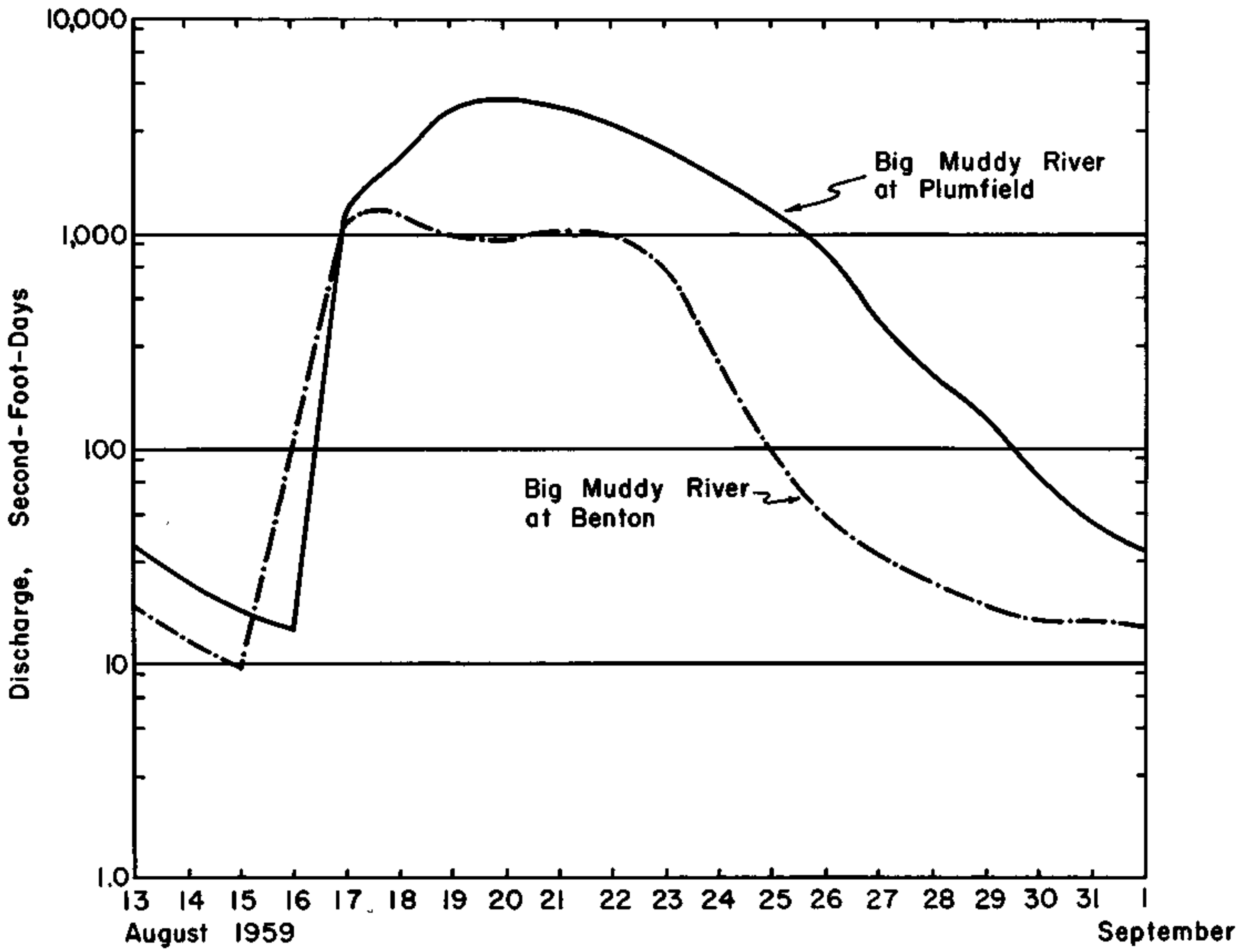


Figure 69. Hydrographs for Big Muddy River at Benton and Plumfield

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